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SUSTAINABLE FUTURES

New research at the intersection of economy, environment and optimization

Environmental
Evidence for better environmental decision-making

Green Innovation
Technology-driven pathways towards sustainability

Resource Efficiency
Optimizing the use of natural and economic resources

JGEOR

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SUSTAINABLE FUTURES

Economy · environment · technology · resilience · optimization

ABOUT THIS ISSUE

The September 2026 issue brings together research on green skills, taxation, professional education and financial reporting, alternative energy in agriculture, urban heat, digitalized financial control and green tourism. Across these themes, the issue treats sustainability as a systems challenge: one that requires economic evidence, environmental responsibility, technological capability and better decisions under real-world constraints.

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FOREWORD FROM THE EDITOR-IN-CHIEF

Toward Sustainable Futures

Dear readers,

JGEOR begins its first volume at a moment when sustainability research is becoming inseparable from questions of economic resilience, technological change, human capital and the efficient use of scarce resources. A sustainable future is no longer only an environmental objective. It is also a question of how economies grow, how institutions adapt, how technologies are governed and how policy choices allocate opportunities and risks across society.

The World Economic Forum's Global Risks Report 2026 places geoeconomic confrontation at the centre of the immediate global risk outlook and notes the intensification of economic and technological risks. At the same time, climate change remains a major long-term structural force. The report's broader framework highlights the interaction of geostrategic shifts, technological acceleration, climate change and demographic change — forces that increasingly shape investment, energy security, public finance, supply chains and institutional resilience.

The Future of Jobs Report 2025 adds another layer to this picture. It identifies technological change, the green transition, geoeconomic fragmentation, economic uncertainty and demographic shifts among the principal forces transforming work to 2030. AI and big data, cybersecurity and technological literacy are rising rapidly in importance, while analytical thinking, resilience, leadership and environmental stewardship remain central. The green transition is therefore not only an energy transition; it is also a skills, governance and productivity transition.

"Sustainable futures require greener technologies, but also resilient institutions, adaptive skills, credible evidence and smarter use of limited resources."

This convergence is why Sustainable Futures is the editorial theme of this issue. For JGEOR, it means resilient economic systems, responsible finance, efficient energy and resource use, adaptive human capital, evidence-based policy and optimization methods that help societies make better decisions under constraints. It also means connecting local and regional evidence to wider global debates while maintaining methodological rigor and practical relevance.

The studies collected here move across economics, education, finance, energy, urban systems, technology and tourism. That breadth reflects the journal's interdisciplinary mission. As Editor-in-Chief, I want JGEOR to develop not simply as a place where papers are published, but as a platform where research is improved through constructive peer review, transparent authorship, ethical editorial practice and open access. Our long-term goal is a credible scholarly culture in which evidence, reproducibility, academic independence and useful debate matter as much as publication itself.

Ulvi Mammadov

Editor-in-Chief · Journal of Green Economy and Optimization Research

Context sources

World Economic Forum. (2026). The Global Risks Report 2026. weforum.org

World Economic Forum. (2025). The Future of Jobs Report 2025. weforum.org

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Strengthening green economy knowledge among youth in Azerbaijan through education and green skills development

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Azerbaijan, green education. green economy, green skills, youth

ABSTRACT

It does not take only technological investments and environmental regulations to make a transition towards a green economy, it also takes a society that understands new models of production, consumption, employment, finance and resource use. Among them, young people are particularly important as their education, career decisions, entrepreneurship and consumption patterns will shape the future trajectory of economic transformation. This paper aims to analyze the potential for building up the knowledge of young people about the green economy in Azerbaijan through education and development of green skills. The use of sources for conceptual and narrative review approach is applied, both international literature and policy documents as well as Azerbaijan-focused studies. Four interrelated dimensions of youth preparedness are identified: conceptual green economy literacy, economic and sectoral literacy, practical green skills and sustainability-oriented decision-making. The study concludes that there is a need to link sustainability education to concrete sectors of the economy, new jobs, green finance, renewable energy and environmental risk management in universities, vocational institutions, public bodies and companies. The development and enhancement of these dimensions can help not only in the environment but also contribute to Azerbaijan's general goals of human resources development, economic diversification and green growth.

INTRODUCTION

The shift towards green economy is now an integral part of current economic and development policy. An inclusive green economy is characterized by a focus on improving human well-being and social equity while minimizing environmental risks and pressures, which typically involves low-carbon development, resource efficiency, cleaner production, circular economy and resilience (United Nations Environment Programme [UNEP], 2019). Transition also needs technological modernization, human capital development in new forms, and diversification in economic activities for countries where development has previously relied on natural resources and fossil-fuel revenues.

The problems that are directly related to Azerbaijan. A clean environment and a country of green growth are recognized as one of the five priorities of Azerbaijan 2030 and the competitive human capital, modern education, and innovation are considered as the strategic development priorities as well (President of the Republic of Azerbaijan, 2021). The World Bank (2022) also sees a potential for the greener growth path to contribute to Azerbaijan's structural diversification and modernization, and the Country Climate and Development Report points to the need to address climate vulnerability and the risk and opportunities emerging from the global transition. (World Bank Group, 2023).

Youth sit at a key nexus of these processes. They are tomorrow's workers, employers, consumers, researchers, managers and policy makers. Their role in green transformation thus requires not just an overall environment sensitivity but also the capability to grasp the interplay between environment goals and finance and investment, jobs, energy, technology, resource management and business decisions. The relevance of youth's knowledge and perceptions of green finance in the Azerbaijani context have already been proved by Mammadov (2025), indicating that green transformation in the financial dimension requires more attention in youth-oriented sustainability studies.

This paper aims with this respect at raising another question than those asked during surveying studies on youth attitudes towards green economy: How can the knowledge of green economy in the segment of youth in Azerbaijan be conceptualized and be reinforced through education and skills development? The goal is to create a practical knowledge matrix that links green economy literacy with skills for education and employment, sectoral perspectives, and informed participation. The study is not based on primary survey data and does not make any statistical claims with respect to the level of the current knowledge of Azerbaijani youth.

LITERATURE REVIEW

Knowledge of green economy beyond environmental awareness.

Environmental awareness and green economy literacy are conceptually different and are closely related. Environmental awareness is a broad concept that relates to the recognition of ecological issues and the need of environmental protection. Green economy literacy needs the added knowledge of how the economic systems, markets, finance, technologies and institutions can respond to those challenges. According to UNEP (2019), an inclusive green economy is one where the objective of human well-being, social equity and reduced environmental risks are combined, therefore, the knowledge on green economy must link ecological goals with economic transformation.

This wider concept is particularly pertinent in Azerbaijan where the green transition processes more and more overlap with finance, renewable energy, and environmental-economic risk management. Mammadov (2025) discusses youth awareness and perceptions of green finance in Azerbaijan, offering first-hand insights into the connection between youth and a financial aspect of the transition. The study by Sadiqov et al. (2026) demonstrates the practical connection between financial mechanisms and investments in renewable energy, specifically highlighting the role of green finance instruments in developing solar energy in Azerbaijan. Another dimension is illustrated by Qadimli et al. (2026) when they connect water-level fluctuations of the Caspian Sea and the strategic inland water system to economic vulnerability. As a whole, these studies demonstrate the need to include the green economy literacy beyond the environmental jargon, and expand it to financial, energy and risk-related knowledge.

Educational process for the development of sustainable education

One of the key pathways for such information to be created is education. Education for Sustainable Development is a process that aims to provide learners with knowledge, skills, values and attitudes that help them make informed decisions and take responsible action, according to UNESCO (2020). This is a broader way of teaching sustainability than just as a single environmental topic. Sustainability related economic transformation has impacts on business, finance, engineering, agriculture, public administration, tourism, urban development and more.

Green economy education for students in economics and management may involve such topics as environmental economics, sustainable finance, circular business models, resource efficiency, green entrepreneurship, sustainability reporting etc. In the field of engineering and technical students, there is a need for more knowledge of renewable-energy systems, efficiency, cleaner production, and sustainable infrastructure. Environmental regulation, climate policy, procurement and transition governance are key areas of knowledge for public-administration and policy students. Incorporating sustainability concepts with other disciplines can therefore help students link sustainability concepts with their individual career paths.

Green skills & employability

Knowledge is of value when coupled with skills. The International Labour Organization reports that as economies move towards a green direction, the skills needed for employment will change, and new jobs will be created with specialized technical skills and transferable skills (Strietska-Ilina et al, 2011). The skills are not restricted to jobs that are termed environmental. Financial professionals might need to be aware of sustainable investment and climate-related risk, accountants might see more environmental reporting, managers might engage with more resource-efficient business models and engineers might be involved with renewable energy and efficiency technologies.

Green skills development can thus contribute to the employability and the entrepreneurship of young people. The educational goal is not to develop a new green profession for each learner, but to incorporate sustainability related competencies in current professions. It is especially pertinent to Azerbaijan and the need for greater interdisciplinary skills and knowledge in economics, technology, finance, and environmental management associated with economic diversification and renewable energy expansion.

MATERIALS AND METHODS

This study uses a conceptual and narrative review. No primary questionnaire, interview, experiment or original statistical data set was utilized. The analytical basis includes selected international policy and knowledge sources on green economy, education for sustainable development, and green skills, as well as official strategic documents and recent academic studies which focused on Azerbaijan.

The sources were analysed thematically based on four questions: What do young people need to learn about the green economy? In what way is the green economy related to national economic sectors? What skills are likely to help young people engage in a greener labor market? What are the potential roles of education in supporting informed decisions about sustainability? In the synthesis, four dimensions of literacy were identified that are interrelated with conceptual green economy literacy, economic and sectoral literacy, practical green skills and sustainability oriented decision-making. The analytical framework is used in the Results and Discussion section in these dimensions.

As the study is a conceptual study, the framework is not designed to assess the current level of knowledge of the Azerbaijani youth. Rather, it categorises areas of knowledge that are pertinent and could be used to inform future educational programmes, curriculum development, non-formal learning activities and empirical research.

RESULTS AND DISCUSSION

Understanding of the concept of "green economy" literacy

The first dimension is related to the understanding of what is green economy. Another issue that is often encountered in sustainability communication is restricting the green economy to the environment, tree planting or renewables only. These are all crucial elements, but resource efficiency, circularity, sustainable production and consumption, social inclusion, resilience, investment and institutional change are also part of the concept (UNEP, 2019). Youth oriented education should thus not only elaborate terms, but also their interconnections.

For instance, circular economy education can link waste reduction and raw-material costs, product design, re-use, recycling markets, and entrepreneurship. Renewable-energy education can link emissions reduction to investment, infrastructure, energy security, skills, and region development. This holistic approach is a way of making environmental knowledge an economic literacy and of making learners aware of the green economy not as a multitude of separate environmental acts, but as a system.

Literacy of economy and sector.

The second dimension is relating to the knowledge about where green transformation takes place in the economy. The national priorities of Azerbaijan are the integration of green growth with human capital and modernization of the economy (President of the Republic of Azerbaijan, 2021). Green Growth is also integrated in the broader context of structural diversification (World Bank, 2022) and the World Bank Group (2023) highlights the economic dimensions of climate vulnerability and the low-carbon transition.

The Azerbaijan-specific research provides concrete instances applicable to education. One such intersection is green finance and renewable energy. Sadiqov et al. (2026) study financial instruments for the development of solar energy and Mammadov (2025) analyzes the knowledge and perceptions of youth about green finance. With these studies, it is now possible to prove that the green economy is not just about environmental objectives, but about decisions regarding capital allocation and investment, financial incentives and risks. Similarly, the analysis of Qadimli et al. (2026) demonstrates how environmental change in water systems can be related to economic exposure, highlighting the need to incorporate environmental-economic risk in green economy literacy.

Youth education can be relevant in the fields of renewable energy, energy efficiency, sustainable agriculture, waste management, circular production, green construction, sustainable transport, water management, environmental services, eco-tourism and sustainable finance. Let students immerse themselves more in the green transition by making them aware of the connection between these sectors and their academic area of specialization and future careers.

Career literacy and practical green skills

The third dimension is going from knowledge to competence. It is important to note that skills development is a key element in achieving the employment potential of a greener economic development as stressed by Strietska-Ilina et al (2011). This means that the universities and vocational schools must integrate theory with implementation. Students can apply their learning through project-based activities, sustainability audits, circular business-model tasks, energy-efficiency tasks, green start-up challenges, and interdisciplinary case studies.

However, career literacy is equally important. Youth should be informed about the change in existing professions in the green-transition context and what other skills they can acquire that might make them more employable. Some of the concepts a finance student might want to learn include green bonds, sustainable lending, and climate risk. General understanding of resource efficient operations and sustainability reporting may be required for a management student. Renewable technologies or energy efficiency may be needed by engineering students. This way, green skills are taught as part of professional development rather than as a stand-alone education sector.

Sustainability-oriented decision-making

The fourth dimension relates to the use of knowledge for personal, professional and social decision making. Going green goes beyond a positive attitude to the environment. Young people should critically consider claims about the environment, understand the compromises involved, explore the costs and benefits of environmental choices, and recognise the difference between substantiated environmental claims and 'green washing'.

This type of literacy can help consumers make decisions, help with entrepreneurship, research, volunteering, professional activity, and civic engagement. It can also improve young people's capacity to assess the value of a proposed green investment for the environment and economy, the environmental and economic risks that impact communities and sectors, and the distribution of costs and opportunities from transition policies. Thus, sustainability-oriented decision making is the confluence of conceptual knowledge, economic understanding and practical skills.

Table 1 provides a four-dimensional matrix for enhancing the knowledge of youth in Azerbaijan on green economy based on the synthesis. The framework is educational, not diagnostic – it defines what should be built, it does not state that the competencies have been already measured in the population.

Table 1. Conceptual framework for strengthening youth green economy knowledge in Azerbaijan

Knowledge dimension	Core content	Expected outcome
Conceptual literacy	Green economy, circular economy, sustainability, resource efficiency	Understanding key concepts and their relationships
Economic and sectoral literacy	Green sectors, diversification, finance, investment, environmental-economic risk	Connecting sustainability with economic development
Green skills and career literacy	Technical and transversal sustainability competencies	Improved readiness for changing occupations
Decision-making literacy	Critical evaluation, sustainable consumption, entrepreneurship, participation	More informed personal and professional choices

The framework indicates that more environmental information towards youth might not be enough. Also, knowledge quality, interdisciplinarity and practicality are important. Azerbaijan is particularly relevant when it comes to four directions of implementation. First, sustainability becomes more systematically part of economics, business, engineering, agriculture, public administration and vocational education. Secondly, the content of education can be connected to the areas and professions in the real world. Third, universities and vocational institutions can broaden the practical learning in the field of green entrepreneurship, applied research and joint efforts with businesses and public institutions. Fourth, communication to young people can be done in language accessible to the young, but with economic and scientific substance.

These measures also explain how green transition and human capital are related. Renewable energy, sustainable finance, water resilience or resource-efficient infrastructure investments can create more long-term value, but with people who are able to operate, finance, manage, and improve those systems. The education for green economy, as a result, should not be approached merely as an awareness raising for environmental issues: it should be considered a part of the economic transformation.

CONCLUSIONS

Even technological and financial investment alone cannot contribute to development of green economy. In addition to that, its long-term success will be contingent on the knowledge, skill and decision making ability of the individuals who will be operating within the transformed economy. The youth are key, as they are at the stage of their professional development at which sustainability, digital transformation, energy transition and economic diversification are increasingly shaping labour markets and business models.

This study suggests that knowledge about the green economy for youth can be seen from four complementary aspects: conceptual literacy, economic and sectoral literacy, practical green skills and career literacy, and sustainability oriented decision making. Development of these dimensions can contribute to the national priorities of Azerbaijan – green growth, competitive human resources, innovation and diversification. Educational institutions can play a role by incorporating sustainability in across areas, making connections to new sectors and jobs, and providing opportunities for real-world applications.

The study is conceptual and fails to measure the current state of knowledge of youth of Azerbaijan. This restriction also outlines a clear path for future research. Independent instruments can be created to gauge the green economy literacy, awareness of green career opportunities, sector-specific skills or the ability to make sustainability decisions with or without pre-existing data. The key policy takeaway is that youth engagement in the green transition should not only be about raising general environmental awareness, but young people need to be empowered to understand and engage with the green transition economic transformation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Mammadov, U. (2025). An empirical analysis of youth knowledge and perceptions of green finance: Evidence from Azerbaijan. Journal of Economics, 2(4), 49–53. https://doi.org/10.36719/3104-4727/5/49-53

President of the Republic of Azerbaijan. (2021, February 2). Azerbaijan 2030: National priorities for socio-economic development. https://president.az/en/articles/view/50474

Qadimli, N., Rasulov, Z., Mammadov, U., & Hasilov, E. (2026). Satellite-based assessment of water level variability and economic exposure in Azerbaijan's Caspian Sea and strategic inland water systems. American Journal of Environmental Economics, 5(2), 31–45. https://doi.org/10.54536/ajee.v5i2.8204

Sadiqov, E., Qadimli, N., & Mammadov, U. (2026). Green finance instruments for supporting solar energy development in Azerbaijan. American Journal of Energy and Natural Resources, 5(1), 18–26. https://doi.org/10.54536/ajenr.v5i1.7984

Strietska-Ilina, O., Hofmann, C., Durán Haro, M., & Jeon, S. (2011). Skills for green jobs: A global view: Synthesis report based on 21 country studies. International Labour Organization.

United Nations Educational, Scientific and Cultural Organization. (2020). Education for sustainable development: A roadmap. UNESCO. https://doi.org/10.54675/YFRE1448

United Nations Environment Programme. (2019). What is an inclusive green economy? https://www.unep.org/explore-topics/green-economy/why-does-green-economy-matter/what-inclusive-green-economy

World Bank. (2022). Azerbaijan: Towards green growth—Issues note. World Bank.

World Bank Group. (2023). Azerbaijan country climate and development report. World Bank Group.

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The role of taxes in the development of the country's economy in modern times

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taxes, tax policy, economic development, state budget, entrepreneurship

ABSTRACT

Taxes not only are significant components in forming financial resources of the state but also in today's economic system have regulatory and stimulating functions. It is especially critical that tax policy is effective in delivering sustainable economic development, funding public spending and social policies and regulating economic activity. The functions of taxes are not only to augment the budget revenues in the present conditions. Tax rates and incentives can affect the decisions of entrepreneurs to start a business, investment, growth of production and the growth of different sectors of the economy, if they are determined properly. The tax reform is an important element of economic policy in Azerbaijan. Over the past few years, a number of steps have been taken towards digitalising tax administration, to foster voluntary tax compliance, to diminish the shadow economy, and to enhance the overall business climate.

This article looks in detail into the fiscal, regulatory and stimulating role of taxes in the context of economic development and investigates the effect of tax policy on entrepreneurship and on investment climate. It also takes into account the key issues affecting tax systems in the contemporary era and explores potential avenues for enhancing their effectiveness. This study shows that one of the conditions for an effective tax policy is to build a proper balance between fiscal interests and economic development goals. An effective tax system can have a positive impact on improving public finances and can facilitate sustainable economic growth, investment and entrepreneurship.

INTRODUCTION

The tax system has become even more relevant in the modern times due to the acceleration of the processes of economic activity, the development of the digital economy, as well as to the increased competition for investment and state financial stability. Taxes are not only a major revenue source for a state's budget, but they are an important tool for a state to influence economic activity (Mankiw, 2021; Musgrave & Musgrave, 1989; Stiglitz & Rosengard, 2015). Thus, problems like the influence of the tax policy on the economy growth, the optimal tax burden level, stimulating the entrepreneurial activity by tax policy, are among the important scientific and practical problems.

Also there are new demand in the tax system in the Azerbaijani economy (Azərbaycan Respublikası, n.d.; Musayev, 2004; Rzayev, 2012; Sharifov, 2011). There is a need to go into further depth in addressing the relationship between taxation and economic growth, given that objectives like the development of the non-oil sector, economic diversification, investment promotion, creation of a competitive environment and combating the shadow economy require a thorough analysis. The State Tax Service's plans for 2025-2028 also involve supporting sustainable economic growth, enhancing the business environment, and fostering entrepreneurship. Evidence from Azerbaijan further suggests that public knowledge and perceptions of green finance are relevant to the broader transition toward sustainable economic development (Mammadov, 2025).

Therefore, the regulatory and incentive aspect of taxes, other than their fiscal role, is very pertinent in today's economy (Mayburov, 2009; Məhərrəmov et al., 2019).

A basic problem of taxation is to find an effective compromise between the interests of taxpayers and the state's budget requirements. A higher level of tax revenues increases the financial capacity of the state budget, but an excessive tax burden can inhibit the entrepreneurial activity, slow down investment decisions and reduce the economic activity in general. In contrast, well thought-out tax supports and tax incentives can stimulate economic growth (Acosta-Ormaechea & Yoo, 2012; Gerson, 1998; OECD, 2010).

In this context, the main difficulty is setting up an optimum tax system which would not only provide the necessary funds to the state but also not hamper economic growth and at the same time would encourage entrepreneurship and investment. The importance of this goes beyond improving tax administration and reducing tax evasion; it's about cultivating trust between the government and the people. Digital technologies are also increasingly a key instrument to tackle these challenges in the digital tax policy (Modica et al., 2018; OECD, n.d.-a; OECD, n.d.-b).

The main goal of the study is to analyze the effects of taxes on the economic development of the country from both theoretical and practical aspects and to understand the importance of tax policy in terms of economic growth, entrepreneurship, investment climate and public finances sustainability in the modern period.

Additionally, the study seeks to assess how current tax systems affect economic activity and what strategies could be used to revamp the tax system. In order to reach this aim, the following tasks are planned:

- To explore the economic nature and basic purposes of tax;
- To decide on the function of taxes in the state budget formation;

- To study the effect of tax policy on economic growth and entrepreneurship;
- To examine the effect of tax concessions and other incentive measures on the investment climate;
- To assess the role of digitalization in today's tax administration; • To assess the role of combating tax evasion and the shadow economy in terms of economic development;
- To analyze the development aspects of tax system in the modern Azerbaijan Republic;
- To develop proposals on how to improve tax policy and make it more effective to support economic development.

LITERATURE REVIEW

The effect of taxation on economic growth has been a longstanding economic policy issue. The existing scholarly approaches show that the effect of the tax system on the economy is not only dependent on the size of the tax rates, but also on the type of tax, the scope of tax base, and the effectiveness of the tax administration. Taxes can affect state economies in terms of labor decisions, investment, entrepreneurship, and innovation as well as state finances. The OECD research focuses on the role of the tax system in economic growth, and indicate that taxes of different varieties affect different economic behaviours (Johansson, 2016; Johansson et al., 2008; OECD, 2010).

Myles' research is a theoretical and empirical analysis of the tax/economic growth nexus. The author emphasizes the need for assessing the effects of tax policy on economic growth taking into account not only taxes but also productive expenditures financed by the government. This way shows that the tax function in economic development goes beyond tax fetching.

Tax effects on investment are also an important topic in the literature. Studies by Vartia in various industrial sectors revealed that an increase in corporate tax rates may have an adverse impact on the inclination to invest while tax provisions for the encouragement of research and development activities may have a positive impact on productivity growth (Johansson et al., 2008).

However, the effect of tax policy on entrepreneurial activity is not as straightforward. Concessions, to small and medium enterprises, can help to grow their business, but a very differentiated tax regime can influence the competitive situation between the different economic entities. Thus, the adoption of tax measures in a more targeted, measurable and economic way is deemed more appropriate (OECD, 2010; World Bank, n.d.).

Studies on Azerbaijan also report that there is a need for improvement in the tax system – namely tax revenue from the non-oil sector, tax administration, and tax base. The IMF has offered suggestions on how to improve tax administration and design the non-oil tax system in its studies of Azerbaijan.

In the modern concepts, digitalisation is also considered as a key factor for the efficiency of the tax system. From the World Bank's point of view, a tax system can help the state provide goods and services, invest in infrastructure and human capital; on the other hand, an excessive tax rate and complicated procedures can have adverse effects on investment and business decisions (World Bank, n.d.).

In general, the literature shows that the relationship between taxation and economic development is multiple faceted. But it is not just a question of a high tax or a low tax; rather it is a question of an optimal tax structure that takes into account economic growth, social equity, and the state's fiscal needs. Results of previous studies also show that the effects of tax policy can differ according to the economic structure and the institutional features of a country (Acosta-Ormaechea & Yoo, 2012; Mourmouras & Rangazas, 2008).

MATERIALS AND METHODS

The methods of the study include systems approach, comparative analysis, scientific generalization, logical analysis and content analysis. The research starts with theoretical aspects on economic nature and role of taxes and then the impact of taxes on economic development processes of the country is identified.

The literature is taken based on reports of international economic organizations, scientific works and official documents on the tax policy of the Republic of Azerbaijan. Various sources gave suggestions of approaches, which were compared to see the similarities and differences.

Comparative analysis was used to compare different facets of the effects of taxes on economic growth, investments, entrepreneurship and public finances. A content analysis was applied to analyze modern trends in tax policy, digitalization of tax administration and factors affecting taxpayer behavior.

Inductive and Deductive methods were also used in the study. Based on the generalization of specific facts in theory and practice, conclusions about the effect of tax policy on economic development were drawn. These methods can be combined for a theoretical and practical evaluation of the topic.

RESULTS AND DISCUSSION

The researches show that, besides being the main source of financing the State in the modern economic system, taxes have an important role in directing economic processes. Taxes bring in state revenues that can be used to finance infrastructure development, education, healthcare, social protection and other public services. The connection between taxation and economic development cannot only be understood by the transfer of money from taxpayers to the state's budget (Musgrave & Musgrave, 1989; Stiglitz & Rosengard, 2015).

How tax policy is formulated is important to its effect on economic growth (Gerson, 1998; Johansson, 2016; OECD, 2010). High tax rates may raise the cost of business, restrict the investment range and in some cases encourage informal activities. In contrast, the right size and structure of the tax burden and an optimised administration can stimulate entrepreneurial activity. Studies by the World Bank also show that a tax structure can help or hinder the growth of the private sector with unwarranted tax levels and burdensome procedures (World Bank, n.d.). Also special attention should be paid to the effect of taxes on investments. What is more important is the stability, transparency and predictability of the tax system for an investor than the tax rate. Thus, a tax policy embracing investment should not only be based on specific incentives, but also create a stable overall business climate.

This is important for the development of the Azerbaijani economy in particular. Recent research on Azerbaijan also highlights the importance of integrating environmental and economic exposure into broader assessments of national development and resilience (Qadimli et al., 2026). In the context of diversification of the national economy and development of the non-oil sector, tax policy's effect on the development of manufacturing, services, innovation and entrepreneurial activity should be taken into consideration (Musayev, 2004; Rzayev, 2012; Shərifov, 2011). The IMF's 2026 assessment also recommends the development of Azerbaijan's tax administration and increase in tax base, as well as the more efficient management of tax incentives.

From this discussion, it is clear that the main aim of the tax policy should not be just to increase revenue for the budget. A balance needs to be struck between raising fiscal revenues and preserving economic activity. The expansion of the tax base, the suppression of the shadow economy, the development of digital tax services and the improvement of the tax administration transparency can be considered as more effective ways in this regard (Modica et al., 2018; OECD, n.d.-a; OECD, n.d.-b).

CONCLUSIONS

From the study results it can be concluded that tax is a multifunctional economic instrument in the development of the national economy. Although their main purpose is to produce state budget revenues, in the modern meaning taxes also serve as an important instrument of economic activity regulation, as a factor of stimulating entrepreneurship, an instrument for shaping investments and the implementation of socio-economic goals (Mankiw, 2021; Mayburov, 2009; Məhərrəmov et al., 2019).

The study shows a balanced and predictable tax policy is essential for its effectiveness to economic development. High tax rates can have a negative effect on economic activity, and poor tax administration and a narrow tax base can reduce the state's fiscal capacity. Hence an optimum tax system should be one which balances the fiscal interests and economic interests of business units (Acosta-Ormaechea & Yoo, 2012; Johansson, 2016).

Digitalization, the streamlining of tax processes, boosting voluntary tax compliance, and combating tax evasion are important tools to ensure this balance in the modern day. International research also shows that taxation is a key element of a strong institutional framework for economic development and productivity (Baer & de Mooij, 2026; Mourmouras & Rangazas, 2008). In sum, a tax policy should be designed not only as a revenue collection tool but as a proactive and adaptable instrument of economic policy in the national interest of long-term development of the country. Proper tax reform can also achieve better outcomes in Azerbaijan if it is oriented towards the objectives of economic diversification, development of entrepreneurship and sustainable economic growth.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Acosta-Ormaechea, S., & Yoo, J. (2012). Tax composition and growth: A broad cross-country perspective (IMF Working Paper No. 2012/257). International Monetary Fund. https://doi.org/10.5089/9781616355678.001

Azərbaycan Respublikası. (n.d.). Tax Code of the Republic of Azerbaijan.

Baer, K., & de Mooij, R. (2026). The art of taxation. Finance & Development, 63(1). International Monetary Fund.

Gerson, P. R. (1998). The impact of fiscal policy variables on output growth (IMF Working Paper No. 1998/1). International Monetary Fund. https://doi.org/10.5089/9781451841602.001

Johansson, Å. (2016). Public finance, economic growth and inequality: A survey of the evidence (OECD Economics Department Working Papers No. 1346). OECD Publishing. https://doi.org/10.1787/094bdaa5-en

Johansson, Å., Heady, C., Arnold, J. M., Brys, B., & Vartia, L. (2008). Taxation and economic growth (OECD Economics Department Working Papers No. 620). OECD Publishing. https://doi.org/10.1787/241216205486

Mammadov, U. (2025). An empirical analysis of youth knowledge and perceptions of green finance: Evidence from Azerbaijan. Journal of Economics, 2(4), 49–53. https://doi.org/10.36719/3104-4727/5/49-53

Mankiw, N. G. (2021). Macroeconomics (11th ed.). Worth Publishers.

Mayburov, I. A. (Ed.). (2009). Taxes and taxation. Yuniti-Dana.

Məhərrəmov, R. B., Mədətova, Ş. Q., & Məmmədzadə, N. R. (2019). Approaches to the study of taxes in theories of economic growth and development. Azerbaijan Tax News.

Modica, E., Laudage, S., & Harding, M. (2018). Domestic revenue mobilisation: A new database on tax levels and structures in 80 countries (OECD Taxation Working Papers No. 36). OECD Publishing. https://doi.org/10.1787/a87feae8-en

Mourmouras, A., & Rangazas, P. (2008). Fiscal policy and economic development (IMF Working Paper No. 2008/155). International Monetary Fund. https://doi.org/10.5089/9781451870138.001

Musgrave, R. A., & Musgrave, P. B. (1989). Public finance in theory and practice (5th ed.). McGraw-Hill.

Musayev, A. F. (2004). Economic problems of tax policy. Elm.

OECD. (2010). Tax policy reform and economic growth. OECD Publishing. https://doi.org/10.1787/9789264091085-en

OECD. (n.d.-a). Tax and development.

OECD. (n.d.-b). Tax policy.

Qadimli, N., Rasulov, Z., Mammadov, U., & Hasilov, E. (2026). Satellite-based assessment of water level variability and economic exposure in Azerbaijan's Caspian Sea and strategic inland water systems. American Journal of Environmental Economics, 5(2), 31–45. https://doi.org/10.54536/ajee.v5i2.8204

Rzayev, P. Q. (2012). The role of tax policy in state regulation of the economy. Azerbaijan Tax Journal, (1), 87–98.

Sharifov, Ə. Ş. (2011). The role of an improved tax system in ensuring sustainable development of the national economy. Azerbaijan Tax News, (9).

Stiglitz, J. E., & Rosengard, J. K. (2015). Economics of the public sector (4th ed.). W. W. Norton & Company.

World Bank. (n.d.). Fiscal policy. World Bank Group.

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The impact of PMS/ACCA-oriented education and IFRS adoption on graduate employability and financial reporting transparency

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IFRS, ACCA, Professional Accounting System, financial reporting transparency, financial education

ABSTRACT

In the context of globalization of capital markets, the use of a single, transparent, and internationally comparable financial reporting language is becoming more essential. This paper reviews two closely related phenomena regarding finance studies, namely, the impact of Professional Accounting System (PMS) and Association of Chartered Certified Accountants (ACCA) oriented educational system on finance graduates' employability and the impact of the adoption of International Financial Reporting Standards (IFRS) on the transparency and the comparability of corporate financial statements. Based on previous empirical and conceptual research, the paper proposes that these two phenomena are not independent, but are mutually reinforcing elements of a single financial system, the professional one: professional education, oriented towards the IFRS, leads to the creation of specialists who can successfully implement IFRS in the practice, while the demand for specialists created by the IFRS implementation increases the value of professionally certified graduates in the market. Four synthesis tables are provided to organize the evidence reviewed, compare the two professional programs, summarize the dimensions of quality of IFRS-based reporting, and present the testable propositions suggested for future empirical research, based on a conceptual framework and a process pathway proposed to organize the identified mechanisms in the literature. The paper concludes that in transition and developing economies like Azerbaijan, the linkage of professional certification curricula with the national accounting education would likely have a positive simultaneous effect on the competitiveness of the labor market and on the quality of the national financial-reporting environment.

INTRODUCTION

The rapid growth of international economic relations and the growing integration of international financial markets in the last 20 years have turned the presentation of financial information in a unified and universally comprehensible format into an operational necessity and not a technical preference. The need resulted in the evolution of a set of principles known as the International Financial Reporting Standards (IFRS), which enables a common conceptual basis for preparing financial statements by companies in different jurisdictions. IFRS is more than just a technical framework for recognition and measurement, it is also a tool for increasing investor confidence, transparency and global economic cooperation.

Meanwhile, the knowledge and skills needed to pursue a career in finance and accounting have changed drastically. Employers today are not satisfied with a university diploma anymore, and they want you to know the international standards and apply them in practice. In this regard, professional papers like the Professional Accounting System (PMS) and the Association of Chartered Certified Accountants (ACCA) have gained special significance. While PMS is designed mainly to grow national professional accounting abilities, ACCA is a global recognised, comprehensive certificate program in the fields of finance, audit, taxation, and management accounting. These programmes are integrated into the university curricula and thus enhance theoretical and practical preparation of students.

A PMS/ACCA-centric teaching model, specifically, gives students the chance to internalize the international standards like the IFRS in-depth and also to set them up better for real working environments. This in turn, enhances the competitiveness of the graduates in the labor market, and helps them to be employed earlier and promoted faster in their working lives.

This paper aims at exploring the impact of PMS/ACCA oriented education on job prospects of finance graduates in an integrated way and also the impact of IFRS implementation on transparency and comparability of corporate financial statements. The importance of this topic is based on the increasing needs of high-level financial specialization in the global context and on methodological problems appearing during the process of national accounting systems' convergence with international accounting standards, which is especially important for developing country accounting systems like Azerbaijan.

The problem that this paper seeks to investigate can be formulated more precisely as follows. Although there is an extensive literature on each of the two issues — labour-market effects of professional accounting certification and reporting-quality effects of IFRS adoption — there is relatively limited literature on the structural connection between the two — namely, IFRS implementation is itself dependent on the availability of professionally trained preparers and the value of professional certification in the labour market is partly a function of the pace of IFRS convergence in a given economy. The novelty of this paper is to call this structural connection, to structure it conceptually and to formulate it as propositions, which can then be tested with empirical data.

This question is of more than academic interest for Azerbaijan specifically, (Qadimli & Mammadov, 2026; Qadimli et al., 2026;

Sadiqov et al., 2026). The speed and content of professional education in accounting is a matter of direct economic impact, particularly as the national accounting system moves towards increasingly using IFRS for their accounting and as more and more local and foreign employers operating in the country demand accounting professionals who are well-versed in IFRS. Knowledge of the relationship between professional certification and the convergence of standards is thus important for the individual graduate who is thinking about his or her career, for the University administrator who is thinking about curricula development, and for the policymaker who is thinking about the timing and the sequencing of accounting reform.

The rest of the paper is structured in the following way. Section 2 examines the literature related to IFRS adoption and the literature on professional accounting education, as well as accounting reform in transition economies in general and Azerbaijan in particular. Section 3 presents the methodology employed in pinpointing and collating the literature. Section 4 outlines a conceptual framework of the two phenomena under study. Section 5 discusses the findings in greater depth and introduces four synthesis tables together with a process-pathway figure. Section 6 discusses implications for policy and practice, Section 7 discusses the contribution and significance of the study, Section 8 explains the limitations of the review and Section 9 concludes.

LITERATURE REVIEW

IFRS: Concept, Rationale, and Global Significance

With the globalization of the world economy, the movement of capital across borders and the evolution and expansion of international economic relations, the need for the presentation of financial information becomes more and more important in a unified, transparent and understandable form (Wadesango et al., 2016). The use of varying national accounting standards by countries makes it difficult to compare financial statements and information asymmetry within the eyes of investors (Mensah, 2021). Hence, from this point of view, the recent move towards the use of IFRS is not only technical but also strategic in ensuring confidence and transparency in the global financial system (Wadesango et al., 2016).

IFRS standards are an internationally accepted system of financial statements standards that can help in preparing financial statements based on common principles. These standards are intended to provide a presentation of financial information that is accurate, objective and comparable. Apart from the transparency it brings to financial information, IFRS adoption also results in better and more dependable information, which allows investors and other users to make better and informed decisions (Mensah, 2021). Ball (2006) casts this as a pro-investor reform: as an investor, the cost of processing and comparing financial information across firms and countries is reduced by a single high-quality set of accounting standards, although Ball notes that the benefits will be heavily contingent upon the enforcement institutions in the adopting country's set of accounting standards.

Concurrently, the use of IFRS helps the analysis of financial performance of companies in different countries. This feature is especially important for international investors, who need information on a standard basis when making a decision about which market to invest in. Additionally, standardized financial reporting increases investor confidence and helps prevent financial manipulation (Mensah, 2021). Therefore, the adoption of IFRS plays a significant role in enhancing the stability of the financial conditions as well as the investment environment (Wadesango et al., 2016).

In developing countries, such as Azerbaijan, the switch from national accounting standards to IFRS has a special meaning. This shift eases the door for local firms to enter the global market and establishes grounds to attract foreign investment which in turn positively affects economic growth and competitiveness in the country.

Other developing and transition contexts provide examples of the potential and the potential conditions of this transition. Ma et al. (2022) conclude that there is a measurable impact on the efficiency of the banking sector in Pakistan associated with the improvement in accounting quality after IFRS adoption and warn that the magnitude of the effects is dependent on the banking-sector ownership structure. However, Maradona and Chand (2018) look at the phased adoption of IFRS in Indonesia and also note that the path to complete adoption is not always straightforward and reporting quality improvements are often incremental as institutional and professional capacity is built over time and the formal changeover to IFRS is implemented. El-Helaly et al. (2020) reinforce this argument by demonstrating that national culture can also affect the effectiveness of IFRS implementation, meaning that we should not assume that IFRS implementation will lead to the same quality of reporting outcomes across countries with different institutional and professional cultures. Poudel et al. (2014) draw a similar conclusion for non-colonized developing economies, highlighting that the institutional and human-capital environment in which IFRS are applied is more important than the standards' substance for their successful application in Nepal.

Professional Certification Programs: PMS and ACCA

However, having a suitable regulatory framework is not a prerequisite for the effective implementation of IFRS. It is also equally important to prepare highly qualified specialists who are aware of international standards for successful executions of this process (Nie & Mastor, 2024). This is where PMS/ACCA oriented educational programmes step in.

Professional certifications like PMS and ACCA are well esteemed and recognized internationally in the field of finance and accounting (Mistry, 2021). These programs offer students valuable hands-on experience as well as theory. The teaching process is designed with real business scenarios, making students learn how to use the knowledge they gain in practice (Nie & Mastor, 2024). In addition, these programs make an important contribution to the development of analytical and critical-thinking skills (Mistry, 2021).

This is one of the major benefits of PMS/ACCA based education that they will get knowledge as per international standards. The ACCA program, especially, emphasizes the understanding of IFRS knowledge and its uses to a great extent. This, in turn, gives them a significant edge in their future work-life (Kwarteng & Mensah, 2022).

Summary of the Core Reviewed Literature

Table 1 provides a summary of the five studies that most directly frame the two research strands that are discussed in this paper: IFRS-driven reporting quality and certification-driven employability; the table shows the study's main research interest and the key findings from the study that are relied on most heavily when discussing the two strands. Beyond this core literature, there are another ten sources that are cited throughout Sections 2, 5 and 6 and are listed in full in the References, which extend the literature to the Azerbaijan and post-Soviet context, to cross-country evidence on IFRS adoption and to psychology of certification-seeking behavior among accounting students.

Table 1. Summary of the Reviewed Literature

Author(s) & Year	Focus	Key Finding(s)
Wadesango et al. (2016)	Impact of IAS/IFRS and regulation on reporting quality	Adoption of IAS/IFRS is associated with improved quality and cross-country comparability of financial reporting.
Mensah (2021)	IFRS adoption and reporting quality in Ghanaian manufacturing firms	IFRS adoption is linked to gains in reliability, comparability, and completeness of financial statements, strengthening investor confidence.
Nie & Mastor (2024)	Employability skills, challenges, and initiatives in accounting	Practical, standards-based skill development is a key driver of accounting graduates' labor-market readiness.
Mistry (2021)	Role of professional accounting bodies in developing employability skills	Professional-body-oriented curricula strengthen employability skills among undergraduate accounting students.
Kwarteng & Mensah (2022)	Skills analysis of accounting graduate employability	Certification-aligned skill sets significantly improve graduates' employment prospects and career progression.

Professional Education and IFRS Implementation Capacity

Today, more and more labor markets are rewarding individuals who not only have the formal certificate but also have the skills proved by practice. Significantly, graduates of PMS/ACCA oriented education are, therefore, perceived as more competitive as compared to other graduates. They find employment in shorter time, earn higher pay and have access to jobs in international companies (Kwarteng & Mensah, 2022). Furthermore, these graduates often have a wider range of career opportunities for their professional growth (Nie & Mastor, 2024).

Empirical studies also show that holders of professional certification programs have higher employment rates, a trend that suggests professional certification programs are highly attuned with the demand of the labor market (Kwarteng & Mensah, 2022; Mistry, 2021). All this evidence together shows that the PMS/ACCA education has a significant contribution in improving human capital in the finance profession.

The quality of financial reporting in turn is generally judged in terms of transparency, reliability, comparability and completeness. IFRS adoption is related to improvement on each of these dimensions (Mensah, 2021). Specifically, the recognition of revenues and expenses would be more precise, the valuation of assets and liabilities would be more accurate, and financial risk would be better disclosed, thus allowing more informed decision making by investors and creditors (Wadesango et al., 2016).

There is a close relationship between PMS/ACCA education and implementation of IFRS. The teaching of IFRS knowledge is one of the main focuses of the ACCA program (Mistry, 2021), while qualified specialists are needed for the effective application of IFRS, and many of these specialists are professionally certified (Nie & Mastor, 2024). In this regard, the education system and the financial reporting system work hand in hand and create a synergy: the better the financial reports, the better the human capital that is developed and the more efficient the financial management (Kwarteng & Mensah, 2022; Mensah, 2021).

Factors affecting employment in finance sector.

In addition to the professional certification per se, accounting and finance graduates' employability literature highlights a number of factors that are important for the success of accounting and finance graduates in the labor market, some of which overlap directly with the PMS/ACCA model. Nie and Mastor (2024) classify them into three general categories: technical competencies (including standards knowledge including IFRS), transferable or 'soft' skills (including communication and analytical reasoning skills), and exposure to practice-oriented or work-integrated learning. They also say that, over the last 10 years, there has been a clear and measurable shift among employers to the second and third types, while requiring technical skill as a minimum.

A complementary perspective is offered by Mistry (2021) who looks specifically on the institutional part of the professional accounting bodies in the creation of employability skills. Her review reveals that undergraduate programs with formal links to professional bodies (such as ACCA) more regularly and systematically include the development of employability skills in the program (e.g. case-based assessment, mentoring by practising professionals, structured internship placements). This indicates that there is at least two pathways through which the employability benefit of PMS/ACCA oriented education can be achieved: a direct pathway, through the technical and standards based knowledge that is assessed for certification; and an indirect pathway, through the pedagogical practices that PMS/ACCA alignment tends to infuse into the surrounding curriculum.

In a more granular analysis of skills, Kwarteng and Mensah (2022) decompose employability into specific skills and demonstrate that graduates with a higher score on the scale of this set of skills have shorter job search experiences. Their results provide empirical evidence to support the idea that the employability premium of an education in PMS/ACCA is not a generic credentialing effect but one that is substantively related to the nature of the content of the PMS/ACCA certification curriculum, of which the knowledge of IFRS is a key component.

A different but related question is why students want to earn professional certificates in the first place. Based on an extended version of the TpB model, Chi et al., (2022) find that perceived capability and perceived career opportunity are the most influential predictors of a student pursuing a certified professional accountancy qualification, with job security having comparatively little influence, in the context of accounting students in Malaysia. In a study of Omani accounting students, Bhat and Khan (2023) also discover that financial reward, market factors, and the work environment are the most significant factors behind the decision to pursue ACCA certification, followed by career exposure and self-competence. The two studies read together indicate that the re-employment benefits reported in other studies in the literature are not a by-product of student decision-making; prospective candidates for ACCA/PMS seem to be conscious of – and motivated by – exactly the labour-market benefits that have been the subject of the outcome studies reviewed above.

Azerbaijan context – national accounting reform and convergence with IFRs

During the last 20 years the accounting system in Azerbaijan has been gradually shifted from the Soviet tax-based reporting system towards a system more oriented to IFRS, especially for public interest entities, banks and large companies that conduct international trade and/or are looking for foreign investments. This convergence process is part of a general trend found in post-Soviet and transition economies where international standards are both technically implemented and given as a sign of institutional credibility to foreign investors and international financial institutions (Golubeva, 2023). In an early comparative assessment of corporate-governance practice in Armenia, Azerbaijan, and Georgia, McGee and Bose (2009) reported that overall the three

Caucasus economies did not score high on several dimensions of corporate governance that are closely associated with financial-reporting practice, highlighting that convergence with international standards has historically had to happen simultaneously with broader institutional reform.

More directly, Valiyev et al. (2021) construct and empirically test a practical consolidation model, which is based on a questionnaire-based fuzzy set analysis of the pros and cons that practitioners see from different consolidation approaches. Their results show what the best consolidation model for Azerbaijan's companies is and, significantly, that one of the more enduring problems faced by respondents is the lack of staff with the expertise to apply IFRS - which directly supports the argument developed in the present paper.

However, as in other transition economies the rate of standards convergence is as effective only as the number of preparers that can apply the new standards and do it well. This is exactly the structural hurdle identified by Nie and Mastor (2024) in their general discussion on the accounting-skills gaps in developing and transitioning markets and also is stated in the Azerbaijan-specific results of Valiyev et al. (2021) that convergence of regulators to IFRS may outpace the domestic supply of IFRS-trained accounting professionals, leaving a transition period when formal adoption of IFRS is not accompanied by uniformly high-quality implementation in practice. One of the main reasons for this is that PMS/ACCA-oriented university education is one of the main ways to bridge this gap, so that the present paper considers professional education and standards convergence as one and the same policy problem, not two different agendas.

MATERIALS AND METHODS

This paper uses a narrative literature review methodology that fits well for synthesizing a still-emerging body of evidence on the joint effects of the adoption of IFRS and professional accounting education. The review relies on peer-reviewed journal articles related to (i) impact of IFRS/IAS adoption on financial reporting quality and (ii) effect of professional accounting bodies and certification program on graduate employability. Sources were chosen with regard to their thematic relevance to the two research strands mentioned above, and were synthesized thematically, not according to a formal systematic-review protocol or as a meta-analysis, since the aim of the paper is conceptual instead of purely empirical.

As is common with literature review papers, no primary survey or firm level data has been gathered for this paper and the tables and figures below are therefore not a report of new empirical statistics, but are instead analytical and conceptual synthesis of the sources reviewed. This distinction is clearly stated here to ensure the reader understands the type of evidence base.

There are three steps in the synthesis. The main theoretical contributions of the sources analyzed are taken out and structured (Table 1). Secondly, the mechanisms that link professional education with capacity for IFRS implementation are mapped in a conceptual framework (Figure 1) and in a process pathway (Figure 2). Third, the reviewed evidence is utilized to formulate a set of propositions (Table 4) that can guide further empirical studies, including studies based on Azerbaijani firm-level and/or graduate-cohort data.

The following two criteria were used to select sources: First, there had to be a source that discussed the reporting-quality consequences of IFRS/IAS adoption or the professional accounting certification consequences of employability in a substantive manner, not as a passing reference. Second, peer-reviewed journal articles were preferred and typically within about the last decade to represent the current state of the IFRS-convergence literature and the accounting-employability literature, both of which have changed considerably in recent years. These sources were then read in full and their central claims, evidence base and scope conditions moved to the structured summary included in Table 1.

It is important to recognize that such a narrative synthesis, which relies on a limited and a purposefully selected group of sources cannot be as comprehensive as a formal systematic review carried out in several bibliographic databases following a pre-registered protocol (e.g. following PRISMA-style reporting). The methodological selection is in line with the aim of this paper, which is not to fully map either of the literatures, but to propose and justify a conceptual framework that connects two.

RESULTS AND DISCUSSION

Based on the literature review provided in Section 2, Figure 1 categorizes the relationship between the professional education and the adoption of IFRS according to the same mediating factor: the availability of qualified financial specialists. PMS/ACCA oriented education provides graduates with the skills needed to interpret and apply IFRS to the requirements of the labour market, which demands such skills to implement IFRS. This interplay of these two forces results in the two-fold effect studied in this paper: better employability of graduates, and better transparency and comparability of financial reporting, which combined represent what the framework calls a "synergistic" benefit of the financial ecosystem as a whole.

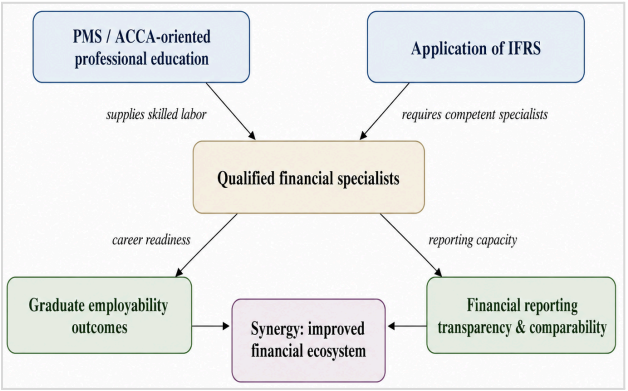

Figure 1. Conceptual Framework: Linking Professional Education, IFRS Adoption, Employability, and Reporting Quality

This framework knowingly focuses on the capacity of qualified financial personnel as a key element of outcomes, and not on professional education or IFRS adoption as the only success factors. This positioning is a reflection of a key premise of the paper: neither PMS/ACCA-focused education nor the adoption of IFRS on its own ensure a higher quality of reporting or better employability outcomes. Instead, each enhances the other's value: IFRS convergence makes professional certification more valuable because employers require more staff members who are knowledgeable about the standards, while a greater number of certified graduates makes it more feasible to implement high-quality IFRS.

Comparative Overview of PMS and ACCA

Although PMS and ACCA share a common orientation toward professional, standards-based accounting competence, they differ in scope and international recognition. Table 2 summarizes these differences as they emerge from the reviewed literature and from the general design of the two programs.

Table 2. Comparative overview of PMS and ACCA program orientation

Dimension	PMS (Professional Accounting System)	ACCA (Association of Chartered Certified Accountants)
Primary orientation	National-level professional accounting competence	Internationally recognized, comprehensive certification
Subject coverage	Core accounting and reporting practice	Finance, audit, taxation, and management accounting
IFRS emphasis	Present, applied within the national context	Extensive, treated as a central curricular priority (Mistry, 2021)
Typical career impact	Strengthens domestic labor-market positioning	Broadens access to international employers (Kwarteng & Mensah, 2022)

Education with a PMS/ACCA orientation and employability of graduates

The literature studied agrees that Higher education that is tailored to professional, certification requirements increases the employment likelihood of graduates in Finance and Accounting. Nieves and Mastor (2024) illustrate the importance of skill development, based on relevant, industry-standard training, for graduates' role readiness in the labor market, while Mistry (2021) highlights how curricula focused on professional body syllabi can enhance graduates' employability skills valued by employers. Kwarteng and Mensah (2022) build on this study by demonstrating that the employment outcomes associated with certification-aligned skills are measurably better – such as quicker job placement and better career progression.

These results in combination indicate that PMS/ACCA oriented education is also a signaling and skill-formation mechanism at the same time. It provides an internationally benchmarked standard of competence and is a concrete indicator of that standard to employers, and it also provides graduate with applied and standards-based skills, including IFRS skills, that are increasingly demanded by employers in the finance sector.

This dual role partly accounts for the fact that the employability effects that have been reported in the literature persist irrespective of the broader conditions in the labour market: employers seem to prefer candidates who have had their skills externally confirmed against an internationally recognised standard because this lowers the employer's cost of assessing the candidate's competence. The signaling channel and the skill-formation channel are thus considered more complementary than competing explanations of the employability advantage of PMS/ACCA education.

IFRS Adoption / Financial Reporting Transparency

Complementary evidence is provided on the reporting-quality side by Wadesango et al. (2016) and Mensah (2021). The former gives the general picture of how IAS/IFRS adoption and related regulatory changes are connected to an improvement in the overall quality of financial reporting observed in jurisdictions, and the latter gives firm-level evidence from manufacturing companies in Ghana that the adoption of IFRS is correlated with measurable improvements in the reliability, comparability, and completeness of reported financial information.

Table 3 lists the dimensions of financial reporting quality that are commonly alluded to in this literature, and the mechanism by which IFRS adoption is claimed to impact each dimension.

Table 3. Dimensions of Financial Reporting Quality Associated with IFRS Adoption

Quality Dimension	Definition	Effect Commonly Attributed to IFRS Adoption
Transparency	Clarity and accessibility of disclosed financial information	Reduces information asymmetry between preparers and users (Wadesango et al., 2016)
Reliability	Faithful representation of underlying economic events	More accurate recognition of revenues, expenses, assets and liabilities (Wadesango et al., 2016)
Comparability	Ability to compare statements across firms and countries	Common recognition and measurement principles across jurisdictions (Mensah, 2021)
Completeness	Extent to which all material information is disclosed	Standardized, principle-based disclosure requirements (Mensah, 2021)

It is important to note that in practice, these four dimensions are not mutually exclusive. The improvements in reliability, for example, are likely to add to comparability because more reliable figures are more readily comparable between firms; and improvements in completeness are likely to add to transparency because a more complete set of disclosure is less likely to be marred by substantial omissions that obscure a firm's actual financial situation. In their review, Wadesango et al. (2016) make a similar point: the literature reports gains in the quality of reporting emanating from the adoption of IFRS frequently occurs at multiple dimensions rather than just one dimension.

The synergy mechanism

The two types of literature mentioned above are not often discussed together directly, but the mechanisms are closely related. This pathway can be followed in five stages as shown in Figure 2: incorporation of PMS/ACCA syllabus (including IFRS) into university curriculum; incorporation of PMS/ACCA syllabus (including IFRS) into curricula of universities training students; greater and better incorporation of PMS/ACCA syllabus (including IFRS) into the curriculum; greater incorporation of PMS/ACCA syllabus (including IFRS) into the curriculum of universities training students; better incorporation of PMS/ACCA syllabus (including IFRS) into the curriculum of universities training students; and higher quality and more comparable financial reporting of the firms that eventually employ the students.

1. Curriculum integration of PMS/ACCA syllabi (incl. IFRS modules)
2. Development of technical & analytical competencies
3. Certification / professional qualification of graduates
4. Employment in finance/accounting roles applying IFRS in practice
5. Higher-quality, comparable financial reporting by employing firms

Figure 2. Pathway from professional education to improved financial reporting outcomes

There is documentation of this pathway in the literature examined, namely in the area of curriculum integration and competency development through the work of Mistry (2021) and Nie and Mastor (2024); of certification and its impact on the labour market through the work of Kwarteng and Mensah (2022); and of the improvement in the quality of reporting once qualified specialists are in practice through the work of Wadesango et al. (2016) and Mensah (2021). The present paper makes the contribution of linking these previously independent findings together in one explanatory sequence.

Propositions for future empirical research

In this paper, the synthesis is based on existing literature and not new data gathered for the purpose of this report, so the central contribution of the synergy mechanism is expressed as a set of testable

propositions. Based on the conceptual matrix (Figure 1) and the pathway (Figure 2), there are four such propositions that are presented in Table 4 to guide further empirical studies, for instance, survey data of Azerbaijan PMS/ACCA graduates or firm-level financial statement data of firms that adopted IFRS.

Table 4. Propositions derived from the literature review for future empirical testing

#	Proposition
P1	Graduates of PMS/ACCA-oriented programs achieve shorter job-search durations and higher starting compensation than graduates of non-certification-aligned programs, controlling for academic performance.
P2	Firms that employ a higher proportion of professionally certified (PMS/ACCA) finance staff exhibit financial statements that score more favorably on IFRS-based comparability and disclosure-quality metrics.
P3	The positive relationship between IFRS adoption and financial reporting quality is stronger in firms with greater availability of professionally certified accounting staff.
P4	Integrating ACCA-aligned IFRS content into national university curricula is associated, over time, with a measurable increase in the employment rate of finance graduates in IFRS-reporting firms.

CONCLUSIONS

This paper has explored, based on a literature synthesis, the combined meaning of IFRS adoption and professional education focused on PMS/ACCA for the finance sector. Both these developments are complementary, and they both contribute to setting the stage to improve the quality of financial reporting, and also to produce competitive specialists for the labor market. Together, they can speed up economic growth, create a better investment climate and enhance financial stability.

The adoption of IFRS improves the transparency, credibility and comparability of financial statements, and thus builds trust in the global financial system. PMS/ACCA oriented education in turn, prepares the professional and skilled manpower, which is essential for effective implementation of these standards. This interplay between two directions helps the quality of financial reporting, and also the competitiveness of graduates in the labour market. A stable platform for economic growth and financial sustainability is thus created, a platform which, as suggested in Sections 6 and 7, deserves the joint attention of universities, professional associations and policymakers.

The analysis indicates that for Azerbaijan in particular, the process of catching up with IFRS based reporting and the growing popularity of ACCA/PMS focused education are not two parallel streams of reforming going on in two parallel streams of institutions, but are two complementary aspects of a single reform process. As illustrated in Figure 2, each of the actors – universities, professional bodies, regulators and employers – has a contribution to make to the mechanism; coordinated action between these actors is likely to lead to faster and longer-term gains in both the quality of national financial reporting and the competitiveness of the finance graduates, than any actor would achieve on their own.

CONFLICTS OF INTEREST

The authors declare no conflict of interest. [Edit if a conflict exists.]

REFERENCES

Ball, R. (2006). International Financial Reporting Standards (IFRS): Pros and cons for investors. Accounting and Business Research, 36(sup1), 5–27. https://doi.org/10.1080/00014788.2006.9730040

Bhat, M. A., & Khan, S. T. (2023). Determinants of accounting students' decision to pursue career as ACCA-certified accountants: A case study of Omani students. Management & Sustainability: An Arab Review, 2(3), 217–238. https://doi.org/10.1108/MSAR-09-2022-0043

Chi, T. K., Yi, T. S., Al Mamun, A., Hayat, N., Salamah, A. A., & Yang, Q. (2022). Predicting the intention to pursue Certified Professional Accountancy Qualification among the accounting students. Frontiers in Psychology, 13, 860204. https://doi.org/10.3389/fpsyg.2022.860204

El-Helaly, M., Ntim, C. G., & Soliman, M. (2020). The role of national culture in International Financial Reporting Standards adoption. Research in International Business and Finance, 54, 101241. https://doi.org/10.1016/j.ribaf.2020.101241

Golubeva, O. (2023). Accounting for transition: A literature review. Journal of International Accounting, Auditing and Taxation, 51, 100548. https://doi.org/10.1016/j.intaccaudtax.2023.100548

Kwarteng, J. T., & Mensah, E. K. (2022). Employability of accounting graduates: A skills analysis. Heliyon, 8(7), e09937. https://doi.org/10.1016/j.heliyon.2022.e09937

Ma, C., Awan, R. U., Ren, D., Alharthi, M., Haider, J., & Kouser, R. (2022). The IFRS adoption, accounting quality, and banking performance: An evaluation of susceptibilities and financial stability in developing economies. PLOS ONE, 17(7), e0265688. https://doi.org/10.1371/journal.pone.0265688

Maradona, A. F., & Chand, P. (2018). The pathway of transition to International Financial Reporting Standards (IFRS) in developing countries: Evidence from Indonesia. Journal of International Accounting, Auditing and Taxation, 30, 57–68. https://doi.org/10.1016/j.intaccaudtax.2017.12.005

McGee, R. W., & Bose, S. (2009). Corporate governance in transition economies: A comparative study of Armenia, Azerbaijan and Georgia. International Journal of Economic Policy in Emerging Economies, 2(3), 228–240.

Mensah, E. (2021). The impact of IFRS adoption on the quality of financial reporting: Evidence from registered manufacturing companies in Ghana. Economic Research, 34(1), 2890–2905. https://doi.org/10.1080/1331677X.2020.1860109

Mistry, U. (2021). Supporting the development of employability skills among undergraduate accounting students through professional accounting bodies. Accounting Education, 30(6), 578–600. https://doi.org/10.1080/09639284.2021.1950016

Nie, Y., & Mastor, N. H. (2024). Employment in accounting: A systematic review of skills, challenges, and initiatives. Cogent Business & Management, 11(1), 2433161. https://doi.org/10.1080/23311975.2024.2433161

Poudel, G., Hellmann, A., & Perera, H. (2014). The adoption of International Financial Reporting Standards in a non-colonized developing country: The case of Nepal. Advances in Accounting, 30(1), 209–216. https://doi.org/10.1016/j.adiac.2014.03.004

Qadimli, N., & Mammadov, U. (2026). Assessing ecosystem sustainability and green finance-based ecotourism opportunities in Akhar-Bakhar National Park. Journal of Green Economy and Optimization Research, 1(1). https://doi.org/10.5281/zenodo.21921560

Qadimli, N., Rasulov, Z., Mammadov, U., & Hasilov, E. (2026). Satellite-based assessment of water level variability and economic exposure in Azerbaijan's Caspian Sea and strategic inland water systems. American Journal of Environmental Economics, 5(2), 31–45. https://doi.org/10.54536/ajee.v5i2.8204

Sadiqov, E., Qadimli, N., & Mammadov, U. (2026). Green finance instruments for supporting solar energy development in Azerbaijan. American Journal of Energy and Natural Resources, 5(1), 18–26. https://doi.org/10.54536/ajenr.v5i1.7984

Valiyev, A., Huseynov, A., Gadimli, N., Huseynov, I., & Elmar, A. (2021). A practical model to implementing IFRS in the national accounting system: The case of Azerbaijan. Journal of Eastern European and Central Asian Research (JEECAR), 8(4). https://doi.org/10.15549/jeecar.v8i4.836

Wadesango, N., Tasa, E., Milondzo, K., & Wadesango, V. O. (2016). A literature review on the impact of IAS/IFRS and regulations on the quality of financial reporting. Risk Governance and Control: Financial Markets & Institutions, 6(4), 102–109. https://doi.org/10.22495/rcgv6i4art13

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Opportunities for implementing alternative energy sources to enhance energy efficiency in agriculture

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ABSTRACT

The establishment of production processes in agriculture based on modern technologies is increasingly increasing the demand for energy resources. Irrigation and drainage systems, pumping stations, greenhouses, storage and processing of agricultural products, as well as the operation of various agricultural machinery and equipment require a certain amount of energy. In particular, the increase in energy prices and the instability of energy supply in some rural areas can seriously affect the costs of farms. In this regard, the use of alternative and renewable energy sources in agriculture is considered one of the important directions from both economic and environmental points of view.

The article reviews the possibilities of using solar, wind, biomass, biogas and small hydropower sources to increase energy efficiency in agriculture. The application of solar energy, especially in the energy supply of irrigation pumps, greenhouses, cold storages and farm buildings, has wide opportunities. Solar-powered pumping systems can help solve the problem of irrigation in areas located far from the power grid. In addition, the conversion of organic waste generated in livestock farms into biogas allows both waste management and additional energy generation.

The analysis shows that the application of alternative energy sources not only reduces energy costs, but also creates conditions for more reliable organization of energy supply of agricultural enterprises. At the same time, reducing dependence on fossil fuels helps to reduce the negative impacts on the environment. The presence of favorable opportunities for the use of solar energy in Azerbaijani conditions, the formation of sufficient biomass reserves in agricultural and livestock farms make the development of this direction even more relevant. However, issues such as initial investment costs, maintenance, the need for energy storage systems and the lack of qualified personnel should also be taken into account. Consequently, the selection of alternative energy technologies in accordance with the characteristics of farms, increasing state support and informing farmers about these technologies can make a significant contribution to improving energy efficiency in agriculture.

INTRODUCTION

Energy supply has always been one of the important issues in the development of agriculture. In modern times, the increase in the number of techniques and technologies used in agriculture further increases energy demand. Each of the processes such as irrigation of cultivated areas, operation of pumps, temperature regulation in greenhouses, cooling and storage of products, and processing of agricultural products requires a certain amount of energy. Therefore, energy costs constitute a significant part of the total production costs in many farms. Traditionally, energy supply in agriculture is carried out at the expense of electricity and various types of fuels. However, changes in energy prices, limited fuel resources and negative impacts on the environment as a result of their use increase interest in alternative energy sources. In recent years, the implementation of various projects related to the application of renewable energy sources such as solar, wind, biomass and biogas in agriculture also shows the importance of this direction. It would not be correct to approach the issue of using alternative energy sources in agriculture only from the perspective of saving electricity. One of the main goals here is to reduce production costs by using existing energy resources more efficiently and to make the energy supply of farms more reliable. For example, solar-powered irrigation pumps can be a convenient solution for providing water to agricultural areas located far from the power grid. At the same time, by obtaining biogas from waste generated in livestock farms, both waste management and additional energy production are possible. This issue is especially relevant for Azerbaijan. The presence of favorable conditions for the use of solar energy in various regions of the country, the large areas of agriculture, and the generation of sufficient organic waste in livestock farms create certain opportunities for the application of alternative energy technologies. At the same time, since the natural and economic characteristics of each region are different, specific conditions should be taken into account when choosing an energy source. The application of alternative energy technologies to

agriculture may be accompanied by certain financial and technical difficulties at the initial stage. The purchase, installation, maintenance, and creation of energy storage systems require additional investment. However, in the long term, the reduction in energy costs, the long service life of equipment, and the reduction of environmental impact make the application of these technologies more expedient. In this regard, the main goal of the study is to investigate the possibilities of applying alternative energy sources to increase energy efficiency in agriculture, to identify their main areas of use and to assess the economic and environmental advantages they can create for agriculture. At the same time, the prospects for using solar, wind, biomass and biogas energy in Azerbaijani conditions are considered.

LITERATURE REVIEW

The issue of energy in agriculture has become one of the most important topics in recent years. The main reason for this is the increase in energy consumption in agricultural production and the impact of energy costs on the cost of the product. In particular, irrigation systems, pumping equipment, greenhouses, and the storage and processing of products require sufficient energy. For this reason, various researchers have investigated ways to use energy more efficiently in agriculture and the possibilities of applying alternative energy sources. In various reports and studies prepared by FAO, the energy supply of agriculture is evaluated in relation to food security and sustainable agriculture. These sources show that energy plays an important role not only during the production of agricultural products, but also in the stages of processing, storage, cooling and transportation of products. Therefore, replacing only one piece of equipment is not enough to increase energy efficiency; it is important to identify and reduce energy losses in the entire production process. Solar energy occupies a special place among alternative energy sources in agriculture. In studies conducted in this direction, the use of solar panels in irrigation pumps has been widely considered. The main advantage of solar-powered pumps is that they can be used for irrigation in fields located far from the power grid. In addition, such systems reduce fuel consumption and save energy costs during long-term use. In addition, the dependence of solar energy on weather conditions and the fact that it does not produce electricity at night may necessitate the use of energy storage systems. Wind energy is also one of the alternative sources that can be used for agriculture. In the literature, there is mainly information about the application of small-power wind turbines in farms, livestock facilities and water pumps. However, the use of wind energy depends more on the characteristics of the terrain than on solar energy. The wind speed and direction in the area where the turbine will be installed should be investigated in advance. Otherwise, it may not be possible for the device to produce energy at any level. The use of waste generated in agriculture as an energy source is also indicated as an important direction in research. Especially in livestock farms, a large amount of organic waste is generated. It is possible to obtain energy as a result of processing this waste in biogas plants. Biogas can be used to produce heat and electricity. Another advantage of this process is that the residues of the material processed in the plant can be used as organic fertilizer in certain cases. Thus, the waste does not create an environmental problem and becomes an additional resource for the farm.

MATERIALS AND METHODS

The main objective of the study is to identify the application possibilities of alternative energy sources in terms of increasing energy efficiency in agriculture and to assess their areas of use. During the study, the most energy-intensive processes in agriculture, the characteristics of alternative energy sources and their application possibilities in various farms were considered. The materials of the study consisted of scientific articles, books, reports, statistical data and information published by relevant government agencies on energy use in agriculture, renewable energy sources and energy efficiency. In addition, materials prepared by international organizations, in particular FAO, IRENA and IEA on agricultural and energy issues, were also used. For Azerbaijan, open data reflecting the current situation in the energy and agricultural sectors of the country were taken into account. The study mainly used the comparative analysis method. The possibilities of using solar, wind, biomass, biogas and small hydropower sources in agriculture were compared with each other, and their advantages and disadvantages were identified. During the assessment, the sustainability of energy production, initial investment requirements, operating costs, the need for technical maintenance and their suitability for various sectors of agriculture were taken as the main criteria. During the study, the main directions of energy consumption in agriculture were considered separately. Irrigation pumps, greenhouses, cold storages, livestock farms and processes related to the processing of agricultural products were evaluated as the main energy consumers. What results can be achieved when applying alternative energy sources in these areas was analyzed based on existing scientific approaches. When assessing energy efficiency, energy consumption reduction and savings that can be achieved through alternativ energy were also taken into account. In a simplified form, annual economic savings can be determined as follows:

$$Q = E \times C$$

Where Q is the annual energy savings, E is the amount of energy saved, and C is the unit price of energy. To determine the payback period of an investment in an alternative energy device, the following expression can be used:

$$T = I / Q$$

Where T is the payback period of the investment, I is the initial investment amount, and Q is the annual economic savings. The study took into account not only economic indicators, but also environmental and technical factors. As a result of the use of alternative energy sources, the reduction of dependence on traditional fuels, the use of waste for energy purposes, and the reduction of greenhouse gas emissions were assessed as possible advantages. In addition, the importance of taking into account the different characteristics of regions when applying alternative energy sources in Azerbaijani conditions was recognized. The level of insolation in the assessment of solar energy, the wind potential of the area in wind energy, and the amount of organic waste generated on the farm for biogas and biomass were considered the main factors. In order to make the results of the study more practical, the application of

alternative energy sources in various agricultural facilities was considered separately. Solar energy was assessed as suitable directions for irrigation systems and farm buildings, biogas for livestock complexes, and biomass for farms with agricultural and processing waste. Thus, the applied methodology allows us to jointly assess not only the technical capabilities of alternative energy sources, but also their economic efficiency and compliance with the real needs of agriculture. The results obtained can be used to identify more suitable alternative energy technologies for increasing energy efficiency in Azerbaijani agriculture.

RESULTS AND DISCUSSION

The results of the study show that the use of alternative energy sources for increasing energy efficiency in agriculture has quite wide opportunities. In particular, the application of solar energy, biogas and biomass in various areas of agriculture can be considered appropriate both in terms of reducing energy costs and improving the energy supply of farms. At the same time, the application of each alternative energy source should be evaluated depending on the size of a specific farm, its location and energy demand.

One of the main directions of the study was the assessment of energy consumption in irrigation systems. During irrigation, the main part of the electrical energy is spent on operating pumping equipment. In this regard, the application of solar-powered pumping systems was assessed as a favorable option for reducing energy costs.

Table 1. Comparison of traditional and solar-based energy supply in the irrigation system

Indicator	Traditional energy system	Solar energy system	Change
Annual energy demand, kWh	24 000	24 000	-
Energy received from the network, kWh	24 000	14 400	-40,0%
Solar energy use, kWh	0	9 600	+9 600
Annual energy cost, AZN	3 840	2 304	-40,0%
Annual energy savings, kWh	—	9 600	40,0%
Estimated annual economic savings, AZN	—	1 536	+1 536

As can be seen from the table, if the annual energy demand of the sample farm is 24,000 kWh, meeting 40% of it with solar energy allows for a reduction of 9,600 kWh of electricity received from the grid. As a result, a certain reduction in energy costs is also achieved. This indicator shows that the application of solar energy, especially in irrigation systems, can be significant from a practical point of view. One of the main advantages when applying solar energy is the reduction of dependence on fuel and the electricity grid. The fact that part of the agricultural areas are located far from settlements and power lines further increases the importance of such systems. It is possible to organize the irrigation process more independently using pumps powered by solar panels. At the same time, the initial investment costs should be taken into account when using solar energy. The purchase of panels, inverters, pumps, control equipment and, if necessary, battery systems creates a certain financial burden for the farmer. However, long-term operation of the system and a decrease in electricity costs may allow the initial investment to be repaid after a certain period of time.

Table 2. Main technical and economic indicators of a solar-powered irrigation system

Indicator	Accepted price
Solar panel system power	10 kW
Annual energy production	14,000 kWh
Annual energy demand of the irrigation system	24,000 kWh
Share of solar energy in demand	58,3%
Energy received from the network	10,000 kWh
Annual energy savings	14,000 kWh
Accepted price of energy	0.16 AZN/kWh
Estimated annual savings	2 240 AZN
Initial investment	18 000 AZN
Simple payback period	about 8 years

These indicators show that the solar energy system can provide interesting results not only from a technical point of view, but also from an economic point of view. However, the payback period may vary depending on solar radiation, equipment price, pump power, annual operating time and electricity price. The application of biogas in agriculture is also one of the directions that can give positive results. Especially in large livestock farms, large volumes of manure and other organic waste are generated. As a result of processing these wastes in biogas plants, it is possible to obtain energy as well as reduce the negative impact of wastes on the environment. The advantage of biogas is that agricultural waste is converted into an additional energy resource here. The gas obtained can be used to produce electricity and heat. The use of the remaining material after the process as organic fertilizer creates additional benefits for the farm.

Table 3. Comparison of the possibilities of applying alternative energy sources in agriculture

Energy source	Main application area	Impact on energy efficiency	Application possibilities
Solar energy	Irrigation, greenhouse, farm buildings	High	High
Biogas	Livestock complexes	High	Medium-high
Biomass	Plant residues, processing waste	Medium-high	Medium
Wind energy	Pumps, farm buildings	Medium	Varies by area
Small hydropower	Water channels, water streams	High	Varies by area
Hybrid systems	Various agricultural facilities	Very high	High

As can be seen from the table, the scope and efficiency of each of the alternative energy sources are different. While solar energy has a wider range of uses, biogas is mainly suitable for livestock farms. The application of wind energy depends more on the wind conditions of the area. Therefore, it would not be right to use the same approach for all farms when choosing an alternative energy source in agriculture. There is also a certain potential in agriculture in terms of the use of biomass. The use of plant residues, straw and other organic materials for energy purposes allows, on the one hand, to reduce the volume of

waste, and on the other hand, to obtain additional energy. However, the costs associated with the collection, transportation and storage of biomass can affect its overall economic efficiency. When applying wind energy, the characteristics of the area are of greater importance. In areas with high wind potential, it is possible to meet a certain part of the electricity demand of farms by using small powerful turbines. However, it is important to collect information about the speed and direction of the wind in the area before installing the turbine. During the study, it was determined that the hybrid use of alternative energy sources is also an effective approach. The combined application of solar and wind energy, as well as the use of battery systems, allows for a more stable organization of energy supply. Such systems are especially important for facilities that require uninterrupted energy, such as greenhouses, cold storages and livestock complexes. In the conditions of Azerbaijan, the application of solar energy in agriculture can be considered one of the most promising directions. The high number of sunny days in many areas of the country creates favorable conditions for the use of photovoltaic systems. In addition, biogas can be considered as an alternative option in farms where livestock farming is developed, and wind energy in areas with suitable wind potential. One of the main issues that attracted attention during the discussion is the initial investment costs. The purchase of solar panels, inverters, pumps, batteries and other equipment for a farmer requires certain financial resources. Therefore, preferential loans, subsidy mechanisms and other financial support tools are of great importance for the wider application of alternative energy technologies in agriculture. On the other hand, the issue of technical service and specialists should also be taken into account. It is important to have specialists with relevant knowledge for the correct installation, operation and technical inspection of alternative energy systems. Educating farmers about these technologies and conducting practical trainings can have a positive impact on the efficient use of the systems. In general, the analysis shows that the application of alternative energy sources in agriculture, in addition to reducing energy costs, can also contribute to a more sustainable organization of production. Solar-powered irrigation systems, biogas plants in livestock farms, and wind energy systems in suitable areas create real opportunities for improving the energy supply of agriculture. In conclusion, it can be noted that when applying alternative energy technologies, attention should be paid not only to the volume of energy production, but also to the initial investment, operating costs, natural characteristics of the area, and the real energy demand of the farm. Based on this approach, the energy system selected can work more efficiently and justify itself in a shorter time. The expansion of alternative energy sources in Azerbaijani agriculture can yield important results in terms of reducing energy costs, improving energy supply, and forming a more ecological agricultural model in the future.

CONCLUSIONS

According to the results of the study, the application of alternative energy sources to increase energy efficiency in agriculture creates significant opportunities from both economic, technical and environmental perspectives. The fact that the main part of energy consumption in agriculture falls on irrigation systems, pumping units, greenhouses, cold storages and livestock facilities makes the application of alternative energy technologies in these areas more appropriate. The study shows that solar energy can be considered one of the most promising alternative energy sources for agriculture in Azerbaijani conditions. In particular, the application of irrigation pumps powered by solar panels allows for reducing electricity costs and reducing dependence on the power grid. According to sample calculations, meeting a certain part of the annual energy demand of the irrigation system with solar energy can create significant savings in energy consumption and annual costs. Another conclusion of the study is that the selection of an alternative energy source should be made in accordance with the characteristics of the farm. While solar energy is more suitable for irrigation and greenhouse systems, biogas can provide more efficient results mainly on large livestock farms. In farms with a lot of crop residues, the use of biomass, and in areas with high wind potential, small-power wind turbines can be considered. The production of biogas and biomass energy from agricultural waste has a positive impact on both energy supply and waste management. In this regard, the application of alternative energy sources is important not only in terms of energy production, but also in terms of converting existing waste on the farm into a useful resource. The research results also show that the combined use of solar and wind energy, as well as the application of energy storage systems, can make the energy supply of agricultural facilities more stable. Hybrid systems are considered promising, especially for greenhouses, cold storage and livestock facilities that require uninterrupted energy. However, there are certain difficulties facing alternative energy systems. The investment required for the initial purchase and installation of equipment, maintenance costs, the cost of energy storage systems and the lack of qualified specialists are among the main problems. State support, preferential financing mechanisms and farmer education are of great importance in overcoming these problems. In general, the results of the study show that the application of alternative energy sources in agriculture allows reducing energy costs, improving the energy supply of farms and reducing negative impacts on the environment. Taking into account the existing natural and agrarian potential in Azerbaijan, it is considered appropriate to expand the application of solar-powered irrigation systems, biogas plants in livestock farms and hybrid energy systems in suitable areas. Consequently, the use of alternative energy sources in agriculture can serve not only energy saving in the future, but also the formation of more sustainable and environmentally friendly agricultural production. In this direction, the implementation of pilot projects taking into account the characteristics of the regions, measuring energy consumption

in real farms and assessing the economic efficiency of alternative energy systems can be considered one of the main directions for future research.

CONFLICTS OF INTEREST

The author declares that there are no financial, commercial, or personal conflicts of interest in the preparation and submission of this article. No external funding, commercial relationship, or other interest that could influence the results of the study has been identified.

REFERENCES

Food and Agriculture Organization of the United Nations (FAO). (2022). The State of Food and Agriculture 2022: Leveraging Automation in Agriculture for Transforming Agrifood Systems. Rome: FAO.

Food and Agriculture Organization of the United Nations (FAO). (2011). Energy-Smart Food for People and Climate: Issue Paper. Rome: FAO.

International Renewable Energy Agency (IRENA). (2016). Renewable Energy for Agri-food Systems – Towards the Sustainable Development Goals and the Paris Agreement. Abu Dhabi: IRENA.

International Renewable Energy Agency (IRENA). (2023). Renewable Power Generation Costs in 2022. Abu Dhabi: IRENA.

International Energy Agency (IEA). (2023). Renewables 2023: Analysis and Forecast to 2028. Paris: IEA.

International Energy Agency (IEA). (2022). World Energy Outlook 2022. Paris: IEA.

Intergovernmental Panel on Climate Change (IPCC). (2022). Climate Change 2022: Mitigation of Climate Change. Cambridge: Cambridge University Press.

United Nations. (2015). Transforming Our World: The 2030 Agenda for Sustainable Development. New York: United Nations.

World Bank. (2020). Agriculture, Food and Energy: Opportunities for Renewable Energy in Agriculture. Washington, DC: World Bank.

Republic of Azerbaijan. (2021). Law of the Republic of Azerbaijan "On Electricity". Baku.

Republic of Azerbaijan. (2021). Law of the Republic of Azerbaijan "On Energy". Baku.

Ministry of Energy of the Republic of Azerbaijan. Data on renewable energy sources and green energy. Baku.

State Statistical Committee of the Republic of Azerbaijan. Data on agricultural and energy statistics. Baku.

Ministry of Agriculture of the Republic of Azerbaijan. Information and materials on the development of the agricultural sector and the application of modern technologies in agriculture. Baku.

Shahbazov, E. M., & Mammadov, R. A. (2020). Directions for increasing energy efficiency in agriculture. Azerbaijan Agrarian Science, Baku.

Aliyev, A. S. (2019). Opportunities for the application of renewable energy sources in agriculture. Energy Problems, Baku.

Meza, F., & Silva, D. (2020). Renewable energy applications in agricultural systems: A review. Renewable and Sustainable Energy Reviews, 134, 110–124.

Pimentel, D., & Pimentel, M. (2008). Food, energy, and society. CRC Press, Boca Raton.

Chel, A., & Kaushik, G. (2011). Renewable energy for sustainable agriculture. Agronomy for Sustainable Development, 31, 91–118.

Kumar, S., & Singh, B. (2021). Solar energy applications in agricultural irrigation systems: A review. Energy Reports, 7, 1234–1248.

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Urban expansion, vegetation patterns and surface heat distribution in Luanda, Angola

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built-up intensity, land surface temperature, Luanda, NDVI, urban expansion

ABSTRACT

Urban growth can significantly affect the characteristics of land cover and surface thermal properties, especially in rapidly expanding African cities, where spatial data is scarce. This study aims at evaluating urban expansion, land surface temperature (LST), vegetation conditions and built-up intensity of Luanda, Angola based on geospatial analysis of satellite-based data. The Global Human Settlement Layer (GHSL) Multi-temporal Urban Extent data were used for investigating the spatial expansion between 2000 and 2025, the Landsat 8 and Landsat 9 Collection 2 Level 2 (CR-LS2025) data were processed for the year 2025 to derive LST, the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Built-up Index (NDBI). Spatial outputs were created using Google Earth Engine and QGIS, and pixel based statistical analysis was used to investigate the relationship between vegetation density and surface temperature after removing water pixels and implausible values. The results show a significant increase in Luanda urban sprawl as well as strong spatial variations in surface temperature and the presence of large high temperature regions within areas of high urban density and low vegetation cover. The analysis of NDVI and LST showed a weak negative correlation ($r = -0.168$; $R2 = 0.028$), implying that higher vegetation density is generally correlated with lower surface temperature, but the amount of thermal variation that can be explained by the vegetation is limited. The results reveal the need of incorporating urban greening, land-cover management and heat-sensitive spatial planning in the future development of Luanda, a city with a fast urbanization rate.

INTRODUCTION

Fast growing urbanization is one of the most significant processes causing recent land-cover change, especially in large metropolitan areas of the Global South. The transformation of vegetated areas, open space and peri-urban landscapes to built-up areas, roads, industrial zones and other impervious surfaces has an impact on the built fabric of the cities, but also on their environmental and thermal properties. Albedo, emissivity, moisture availability and heat-storage capacity and aerodynamic properties of urban surfaces are typically different from natural land covers. Therefore, urban growth can affect surface energy balances, evapotranspiration and help to cause spatial hotspots of land surface temperature (LST). These processes have fostered the interest of academic and policy communities in the understanding of the relationship between the urban expansion and surface thermal conditions using a spatially explicit approach (de Almeida et al., 2021; Ngie et al., 2014).

Urban growth has some thermal implications that are relevant to several dimensions of sustainable development. Unbearable surface temperatures, which can be caused by hot conditions for extended periods, can lead to further energy and environmental inequity, greater cooling requirements, and strain to energy and urban infrastructure. Urban thermal conditions are also linked to spatial distribution of vegetation, surface materials, built-up density and water bodies and therefore heat cannot be discussed without considering the dynamics of land-use and land-cover. Therefore, the study of the urban surface temperature is now an interdisciplinary research domain that encompasses urban climatology, environmental management, remote sensing, urban spatial planning and sustainability research. A systematic review of urban heat studies using remote sensing data from 2000 to 2020 revealed by de Almeida et al. (2021) showed that Landsat products had a wide range of applications, with LST and LULC being the most common, and that among the statistical methods used in UHS, correlation and regression were among the most common. The evidence shows the increasing use of satellites to monitor environmental changes in large areas where traditional ground-based monitoring networks cannot adequately cover the ground.

Urban heat island (UHI) is a term that is often used to refer to the heat island phenomenon of urbanized areas being hotter than their rural surroundings. There is, however, a significant difference between the urban heat island based mainly on the near surface air temperature and the surface urban heat pattern measured from remote sensing based LST. Land surface observations from satellite thermal sensors can be used to assess the spatial thermal heterogeneity in detail throughout an urban landscape, as it acts as an observation of the radiative temperature of the land surface. In the current investigation, the focus is on the land surface temperature patterns instead of the formal determination of a land surface urban heat island intensity based on a specified rural reference area. This is a methodologically relevant distinction since remotely sensed surface temperatures are interpreted depending on the land-cover composition, acquisition conditions, seasonality and definition of the study area.

Remote sensing in particular is significant for the fast-changing African cities. While there is an increasing number of urban heat

studies around the world, coverage is not uniform. Previous studies indicated that satellite-based heat studies have focused mainly in Asia, Europe and North America, leaving African cities underrepresented (Ngie et al., 2014). There is growing consensus that remote sensing is now the preferred method for assessing surface heat conditions in urban areas across Africa, as a weather-station network is not necessarily spatially dense enough to capture intra-urban thermal variability (Gyimah, 2023). Meanwhile, Africa's urban centers undergo some of the most dynamic demographic and spatial changes anywhere in the world. These situations make it imperative to adapt the studies to the needs of individual cities and to be able to quantify the impact of urbanisation on the environment instead of assuming that the results of studies in well-known cities in other parts of the world can simply be exported to African urban areas.

Luanda offers a prime example of such an analysis. The capital and biggest metropolitan centre in Angola, the city has grown vastly in peri-urban areas and reclaimed previously undeveloped land. The urban morphology of the metropolitan area has been gradually altered by rapid population concentration, residential development and transport infrastructure and urban sprawl. The vast extent of this process has previously been shown by remote-sensing studies. Ngolo and Watanabe (2023) reported that Luanda's built-up area increased from approximately 94.5 km^2 in 2000 to 198.3 km^2 in 2008 and 468.4 km^2 in 2018. Their results show that Luanda is not only going through a process of incremental urbanisation, but one that is also characterised by a new spatial restructuring of the metropolitan area. An important environmental question in this context is how these shifts in land-cover are manifested in the current spatial distribution of surface temperature, vegetation and built-up characteristics.

This question is of special relevance, given that Luanda has several features that make environmental analysis in the city complex. The city lies on the Atlantic coast, has developed areas with a high density of urban development and fast-growing peri-urban areas and is surrounded by land surfaces that can be covered with sparse vegetation, dry or bare soil, and mixed peri-urban land uses. Such diversity may lead to significant spatial differences in the satellite-derived thermal and spectral indices. Local cooling effects may be provided by proximity to the coast and heat storage effects can be enhanced by dense impervious surfaces. Shading and evapotranspiration from vegetation can help to moderate surface temperatures, while exposed and dry surfaces even if not intensively urbanized, can have high daytime temperatures. For this reason, it is better to interpret the multi-indicator rather than only one of the surface temperature or built-up indices.

The Normalized Difference Vegetation Index (NDVI) is one of the most popular satellite-derived indicators, which reveals the availability and abundance of vegetation, and is often used to explore the cooling effect of urban greenery. This is due to the fact that in many urban areas, vegetated surfaces redistribute the energy received via evapotranspiration and have different radiative and thermal properties as compared to impervious surfaces (de Almeida et al., 2021). However, the intensity of this relationship can be significantly influenced by several factors such as climate, type of vegetation, urban morphology, season, and spatial scale. Therefore, the statistical analysis of the relationship between NDVI and LST strengthens the basis for interpreting the results, rather than relying on a simple visual relationship between maps.

Normalized Difference Built-up Index (NDBI) offers another view by highlighting spectral differences related to built-up surfaces. But in dry and semi-arid areas, its interpretation should be done with special care. However, Rasul et al. (2018) indicated that conventional NDBI could find it difficult to separate constructed surfaces from bare or dry soil as both land-cover types can have similar spectral properties. The authors demonstrated its ability to significantly impact the built-up mapping accuracy in dry climate cities and suggested some indices for the discrimination of urban and bare soil surfaces. This methodological limitation is very pertinent in Luanda. Thus, in the current study NDBI is used as an indicator of built-up intensity or as an indicator of the spectral surface characteristics and not as an unquestioned built-up classification of all urban land. It is interpreted in conjunction with urban extent, LST and NDVI evidence. This type of hybrid method minimizes the chance of assigning all of the high NDBI values solely to buildings and impervious development.

Multi-source geospatial data also enables the present-day thermal conditions to be put into a longer-term urbanisation context. The Global Human Settlement Layer (GHSL) is a standardized spatial database to investigate the past spatial evolution of human settlements and Landsat is a long time and well validated environmental monitoring record. The incorporation of multi-temporal settlement data with LST, NDVI and NDBI derived from Landsat data allows two complementary aspects of analysis: (1) how the spatial extent of Luanda has evolved over time; and (2) how the current urban landscape is varying in terms of its thermal, vegetation and built-up properties. This built-in logic aligns with wider satellite-derived environmental assessment methodologies that involve merging environmental indicators with spatial data to prioritize areas for exposure and/or vulnerability or management (Qadimli et al., 2026).

This type of environmental assessment applies to the broader green-economy transition as well. To achieve sustainable urbanization, besides the recognition of environmental pressures, spatial evidence has to be transformed into investment priorities, planning interventions and nature-based responses. The integration of ecosystem assessment with green finance provides a testament to the value of spatial environmental priorities to guide restoration, conservation, and sustainable economic activities (Qadimli & Mammadov, 2026). Likewise, increased financing for green finance instruments can facilitate infrastructure investments that benefit the environment and the development of low-carbon options (Sadiqov et al., 2026). Similar mechanisms can be used to invest in green infrastructure, urban tree canopy, climate-responsive public space, reflective and permeable surfaces and other measures that enhance thermal resilience – in an urban setting. The social acceptance of green-transition measures is also closely connected to the environmental awareness: Research has investigated the knowledge and perceptions of green finance and sustainability-related instruments (Mammadov, 2025).

Urban environmental quality is by its nature multi-dimensional. Exposure to heat is not in isolation to other anthropogenic stressors like transport, industry and air pollution. It is observed that studies on particulate matter in urban-industrial environments have highlighted the role of economic, industrial and transportation interactions as the key drivers to influence the environmental conditions and not a single factor (Arifzade et al., 2026). While this current study does not directly examine air pollution or industrial emissions in Luanda, this overall evidence further supports the idea of looking at thermal patterns as part of an integrated urban environmental system. In areas with high levels of development, low vegetation cover and high levels of infrastructure, environmental pressures may be experienced simultaneously and spatial analysis can be applied to identify areas that may require more detailed planning and field-based investigations.

Although there has been an upsurge of academic concern about African urbanization, one crucial research gap that has yet to be addressed is the Luanda situation. Previous research has yielded important findings regarding urban sprawl and land use/ land cover classification, especially the extent of spatial growth in the urban area (Ngolo & Watanabe, 2023). On a continental level, review studies also demonstrated the relevance of remote sensing in the field of urban heat in Africa (Gyimah, 2023; Ngie et al., 2014). But, little attention has been paid so far to the integration of Luanda's recent urbanization with the current LST, vegetation conditions and built-up intensity in a geospatial unified framework. Furthermore, the ecological importance of these patterns should be interpreted with caution and statistical analysis, since the dry, and somewhat heterogeneous, surface properties of the metropolitan region may reduce the effectiveness of simple correlations between standard spectral indices and temperature.

The filling of this gap is of relevance on both scientific and practical aspects. Luanda is both a scientific challenge to investigate if the common assumptions on the relationship between vegetation, built-up properties and surface temperature are still valid in a fast-growing coastal African city. Planning-wise, spatial thermal heterogeneity can be used as a planning indicator for where future development should take more care to consider vegetation conservation and heat-sensitive design (urban greening). The aim is not to draw conclusions about causality from the satellite-derived correlations alone, but to provide a spatial evidence base that is reproducible and can be used to help inform more in-depth environmental assessment and policy analysis.

The main objective of this study is therefore to evaluate the urban expansion and LST patterns in Luanda city, Angola, through a geospatial analysis based on satellite data. The research has three main aims. First, the spatial evolution of Luanda's urban extent, between 2000 and 2025, is examined with the help of multi-temporal Global Human Settlement Layer data. Second, it provides a map of the land surface temperature, vegetation and built-up intensity of the current time (2025) based on the Landsat 8 and Landsat 9 Collection 2 Level 2 imagery, with the LST, NDVI, and NDBI indicators. Thirdly, it statistically examines the correlation and regression between vegetation density and land surface temperature after excluding water surfaces and implausible observations on a pixel bases. Satellite-image processing and the calculation of indicators is done using Google Earth Engine; spatial visualization and cartographic production is done using QGIS. This integration of the components allows an integrated assessment of Luanda's recent urban transformation and its contemporary surface thermal environment and aims to bring useful evidence to the table needed for climate responsive spatial planning, urban greening and sustainable metropolitan development.

LITERATURE REVIEW

The link between urbanization, land-cover change and surface temperature has emerged as a large research area in the disciplines of urban climatology and remote sensing. City physical sprawl substitutes natural and semi-natural surfaces with buildings, road networks and other impervious surfaces which alter surface energy balance and leads to spatial variations in temperature. Thermal infrared remote sensing has gained even more significance for assessing these processes as it provides the possibility to observe land surface temperature (LST) repeatedly and continuously over a mosaic of urban land cover, instead of at meteorological stations only. Weng (2009) remarked that thermal remote sensing observations can be used to explore the spatial variations of LST with vegetation, land use, surface parameters and urban structures, and recent methodological reviews have highlighted the importance of satellite-based thermal remote sensing in current thermal studies in urban areas (de Almeida et al., 2021; Shi et al., 2021).

Given the inclusion of thermal observations, multispectral bands, medium spatial resolution and long historical record, Landsat imagery has been predominant in this literature. de Almeida et al., (2021) conducted a systematic review of urban heat studies using remote-sensing data that occurred between 2000 and 2020, they concluded that Landsat products are the most commonly used in both the retrieval of LST and the analysis of land use and land cover. Correlation and regression were also frequently used statistical methods, highlighting the need to step beyond visual mapping, and to quantitatively investigate relationships between urban surface properties and thermal variables. In turn, Shi et al. (2021) emphasized the development of thermal data processing, multi-sensor analysis, image fusion, and cloud-based platforms by remotely sensed thermal data, and emphasized that the interpretation of LST is still dependent on the characteristics of the sensors, the spatial resolution, the acquisition conditions, and the method to be used.

One of the key questions is how surface temperature relates to vegetation abundance in this research. Evapotranspiration, shading and changes in surface radiative properties are all factors that can limit the surface heating during the day with the presence of vegetation. As a result, the Normalized Difference Vegetation Index (NDVI) has been commonly used as an indicator of vegetation density in studies of urban thermal environment. An influential study about the relationship between vegetation abundance and LST derived from Landsat imagery by Weng et al. (2004) proved the importance of spectral vegetation information in understanding intra-urban temperature variation. Their research also revealed that the spatial complexity of urban thermal environments exists, and the relationship between vegetation and temperature could be dependent on how the vegetation abundance is represented.

Subsequent studies have continued to prove the value of the vegetation indicators and revealed an not-constant relationship between them and temperature. For instance, Yuan and Bauer (2007) have examined the association between surface temperature and the urban landscape using two variables, NDVI (as a measure of surface urban heat characteristics) and impervious surface area. They argue that their results indicate that vegetation and imperviousness are complementary and not competing aspects of the thermal analysis of the city. The implication is that high temperatures cannot be interpreted in isolation as an effect of low vegetation, and that the spatial layout and coverage of impervious materials are also key.

Background climate also modulates vegetation related cooling. Manoli and others (2019) showed using a global analysis of urban–rural surface temperature differences that the intensity of the urban heat effect is systematic as a function of both climatic and population factors. Their findings indicated that the urban-rural difference of evapotranspiration and convection can significantly influence the urban warming and that effectiveness of mitigation options (green cover) can be different in different climatic regions. This finding has important implications for warm or relatively dry cities since the effect of vegetation–temperature relationships found in temperate cities may not be directly applicable to these conditions. It also gives a theoretical background to the NDVI–LST relationship that can be used to make this relationship an empirical issue and not assume a predetermined relationship strength.

The other side of this relationship is built-up land. Built-up indices are generally used to describe built-up conditions as urban construction

materials or impervious surfaces store and release heat differently from vegetated surfaces. In cities with large areas of exposed or dry soil, however, care must be taken in interpreting NDBI. Rasul et al. (2018) investigated built-up and bare-soil indices obtained from Landsat 8 data in dry-climate cities and concluded that the spectral resemblance between built-up surfaces and bare soil can significantly affect the discrimination between these two types of surfaces. This restriction becomes significant in the case of fast-growing cities, where peri-urban areas might consist of new built-up units, sparsely vegetated land and bare soils. Thus, NDBI can only be interpreted in conjunction with other independent information on extent of urban development and vegetation and LST, and not as a sole binary indicator of urban development.

Such methodological issues are particularly relevant for Sub-Saharan African cities. Ngie et al. (2014) reported that the number of studies on urban heat using remote sensing data was relatively small in Africa when compared to the Americas, Europe and Asia, despite the fast pace of urbanization taking place in Africa. The authors explained that satellite remote sensing is of particular value where ground based temperature networks lack spatial coverage. Almost a decade later, Gyimah (2023) also found that the use of remote sensing was predominant in the surface urban heat studies in Africa and the main factors contributing to the rise in thermal stress included urbanization and vegetation degradation. The methodological gaps continue to highlight African urban environment as an important area for city-specific remote-sensing research.

The African context also shows how urban thermal processes cannot be seen as simple linear relationships between development and temperature. From one continent to the other, cities have varied climatic conditions, plant resources, population density, building materials and infrastructure. The results of Manoli et al. (2019) revealed that background hydroclimatic conditions affect urban warming magnitude, and Rasul et al. (2018) indicated that dry surface characteristics affect the interpretation of conventional built-up indices. These studies suggest that, together, analyses of African cities should incorporate several spatial indicators, and recognize situations where relationships are not linear and/or weak. A weak statistical relationship could therefore be a meaningful characteristic of a heterogeneous urban system and not just an analytical failure.

Luanda provides an example of how remote sensing technology can be used and what evidence is still missing. Ngolo and Watanabe (2023) used GIS, remote sensing and machine-learning to analyze urban growth in Luanda and found that built-up area has grown significantly from 94.5 km² to 198.3 km2 to 468.4 km2 from the years 2000, 2008 and 2018 respectively. They also found a strong relationship between expansion and existing residential development, major road network and government housing programmes. This study offers one of the most significant empirical bases for the knowledge of the recent spatial transformation of Luanda and the result is a clear proof of the recent restructuring of the city region in a way of rapid peripheralization and not of gradual centralization.

Meanwhile, the definition of urban spatial units has been gradually uniformed. The Global Human Settlement Layer and its Urban Centre Database offer harmonized spatial representations and allow urban centres to be compared in a consistent manner across time and space. Melchiorri et al. (2024) characterized the Global Human Settlement Urban Centre Database as a multi-temporal and multi-dimensional database that integrates the spatially explicit city boundaries with demographic, geographic, environmental and socioeconomic data. This kind of uniform urbanization is especially useful for longitudinal analysis as the administrative boundaries may not exactly match the physical spread of an urban agglomeration. This offers a suitable model for the assessment of Luanda's urban growth over time and in combination with current environmental indicators derived from satellite data.

However, the environmental implications of Luanda's sprawl have not been studied as much as the sprawl itself. Current studies show where and how quickly the city has grown but the link between this new urban area and the current thermal situation is not well characterized. This gap can be mitigated with a combined analysis of urban extent, LST, NDVI and NDBI, which can help to correlate the urban expansion in the past with the current surface conditions. This aligns with the prevailing remote-sensing research that stresses that LST should be analyzed along with various land-surface indicators instead of using it as a single indicator (Shi et al., 2021; Weng, 2009; Yuan & Bauer, 2007).

In addition, the literature indicates that urban thermal analysis also has practical applications outside of the physical geography field. Although the design of measures for heat mitigation can be achieved through green infrastructure and urban vegetation and through more climate-sensitive land management, we need spatial evidence to show where the heat is concentrated and how it relates to the land-cover conditions. At a higher level of sustainability, environmental assessment may help prioritise investments and allocate resources to more environmental-friendly modes of development. The growing importance of environmental evidence in planning and investing decisions is illustrated through research on the relationship between geospatial environmental assessment, economic exposure and green-finance considerations (Qadimli et al., 2026). In this regard, green finance has the potential to facilitate nature-based and sustainability-oriented interventions as stated in ecosystem-based assessment (Qadimli & Mammadov, 2026).

Combined, prior research highlights four key points. First, Landsat based LST is an established method to investigate the urban surface thermal heterogeneity (de Almeida et al., 2021; Shi et al., 2021; Weng, 2009). Secondly, vegetation and impervious/Built-up features are also important but context-dependent explanatory factors which need to be interpreted in an integrated manner rather than separately (Rasul et al., 2018; Weng et al., 2004; Yuan & Bauer, 2007). Thirdly, although African cities are experiencing a high rate of spatial growth, they are still underrepresented in the global urban thermal literature (Gyimah, 2023; Ngie et al., 2014). Fourth, although Luanda has undergone dramatic urban expansion, there is limited integrated evidence that links multi-temporal urban growth with current LST, vegetation and built-up attributes (Ngolo & Watanabe, 2023).

In this study, the authors have contributed to the above literature by integrating standardized urban-expansion data with LST, NDVI and NDBI derived from Landsat for the city of Luanda. The relationship between vegetation and built-up intensity and temperature is not assumed, but tested and interpreted based on the empirical analysis conducted in the study, considering the fact that Luanda is a complex and coastal city, with a very dynamic urban growth. This is to build on current mapping of urban growth and move towards a more holistic knowledge of the environmental parameters related to urban growth.

MATERIALS AND METHODS

Study area

It concentrates on Luanda, the capital and biggest metropolitan area of Angola on the Atlantic coast of south-western Africa. Given the wide metropolitan area, the high diversity in land-cover and the mix of densely built-up areas, peripheral growth areas, bare surfaces, coastal areas and discontinuities in vegetation, Luanda is a suitable case study

for the analysis of the interplay between rapid urbanisation and current surface thermal conditions. Past studies using remote sensing have reported a significant expansion of the urban area of Luanda since the turn of the twenty-first century (Ngolo & Watanabe, 2023).

The analysis was based on the urban-centre representation from the Global Human Settlement Layer (GHSL) World Urbanisation Prospects 2025 framework, which was not constrained by administrative boundaries. This method is useful for analysing the temporal evolution of a metropolitan area's spatial extent within an urban system that is constantly growing, given that it produces urban-centre geometries consistent between the different time periods (Pesaresi et al., 2024; Schiavina et al., 2025).

To perform the environmental analysis using the Landsat data, an analysis extent containing Luanda and the surrounding peri-urban area was determined in Google Earth Engine (GEE) as a rectangle. The extent was chosen intentionally to be wider than the central built-up area to include spatial variation in urban, peri-urban, vegetated, bare-surface and coastal environments. To ensure spatial consistency with the outputs of the rasters, the same analysis extent was applied for the LST, NDVI and NDBI computation for 2025.

Data sources

The two main geospatial data sets used were: The European Commission Joint Research Centre GHS-WUP-MTUC R2025A multi-temporal urban-centre information was used. The product includes urban-centre polygons connected to statistics over multiple epochs and includes population and area/built-up surface data for urban centres all over the world (Schiavina et al., 2025). Luanda was found in the database by ID_UC_G0 = 939 and the polygons for the 2000 and 2025 epochs were extracted and compared.

The time status of the GHSL-WUP information is important to distinguish. The R2025A framework used for the construction of the R2025A framework combines historical estimates with the World Urbanisation Prospects projection framework, so the 2025 epoch should be interpreted as the respective GHSL-WUP R2025A urban-centre representation and not as a separately field surveyed administrative boundary. This distinction was maintained in the understanding of temporal change.

Surface environmental conditions were calculated based on the following Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) Collection 2 Level 2 imagery and Landsat 9 OLI-2/TIRS-2 Collection 2 Level 2 imagery. The Level-2 products are atmospherically corrected surface reflectance and surface temperature bands with a 30-m spatial resolution and are analysis ready data that can be used for environmental and urban applications (Earth Resources Observation and Science [EROS] Center, 2020).

Table 1. The main data and analytical applications

Dataset	Period / epoch	Spatial resolution	Main application
GHS-WUP-MTUC R2025A	2000 and 2025	1 km source framework	Urban extent comparison
Landsat 8 OLI/TIRS Collection 2 Level 2	January–April 2025	30 m	LST, NDVI and NDBI
Landsat 9 OLI-2/TIRS-2 Collection 2 Level 2	January–April 2025	30 m	LST, NDVI and NDBI
QA_PIXEL	January–April 2025	30 m	Cloud, cloud-shadow and cirrus masking
OpenStreetMap	Contemporary basemap	—	Cartographic reference for selected figures

Satellite processing and pixel-based statistical analysis were performed on Google Earth Engine (Gorelick et al., 2017), a cloud-based geospatial computing platform to allow large-scale analysis of remotely sensed data. All rasters were downloaded from GEE as 30-m GeoTIFF images.

For cartographic visualization, preparation of raster symbology, comparison of urban extent, preparation of legend and scale-bar, and export of publication-quality maps, QGIS 3.x was used. The figures were exported as 300 dpi. The map of urban-expansion was produced using OpenStreetMap as a contextual basemap, while the NDVI and NDBI values were mostly used as analytical raster surfaces, lacking a basemap.

Selection and pre-processing of Landsat images

Landsat 8 and Landsat 9 Collection 2 Level 2 image collections were merged and subsetted for the time period from 1 January to 30 April 2025 and for the Luanda study area. A multi-image period was chosen, instead of a single acquisition, to minimize the dependence of the results on the atmospheric conditions of each individual scene and the possible presence of residual cloud contamination.

The QA_PIXEL quality-assurance band was used to remove cloud-contaminated pixels. The Landsat quality mask was used to remove cloudy pixels: bits 3 and 2, for cloud and cloud shadow/cirrus, respectively. The scenes available were combined pixel-wise using a median composite after masking. To maintain the surface signal as the most significant contribution during the period of analysis, median compositing was chosen to minimize the impact of "bad" data.

An official U.S. Geological Survey scaling relationship was used to convert the Collection 2 Level 2 surface reflectance digital numbers to physical reflectance values:

$$SR = (DN \times 0.0000275) - 0.2$$

where (SR) is the surface reflectance and (DN) is the original digital number. Scale and offset values are based upon the Landsat Collection 2 Level 2 product specification (EROS Center, 2020).

Retrieval of Land surface temperature

The Landsat Collection 2 Level 2 ST_B10 band was used to derive landsurface temperature. As ST_B10 is already an existing Level-2 surface-temperature science product, there was no independent surface temperature reconstruction from top-of-atmosphere radiance and emissivity. Instead, the official Collection 2 scaling coefficients have been used.

The temperature in Kelvin was calculated by:

$$T_k = (DN \times 0.00341802) + 149.0$$

and then changed to degrees centigrade:

$$LST = T_k - 273.15$$

where T_k is the surface temperature in Kelvin, and LST is the land surface temperature in degrees Celsius. The multiplicative factor (0.00341802) and additive offset (149.0) values apply to the official scaling parameters used to calculate surface temperature from Landsat Collection 2 data (EROS Center, 2020).

The median LST raster was clipped to the overlapping study area and exported with a resolution of 30-m. For visualization, a continuous cool to warm colour ramp was applied, with the blue-green tones showing the lower temperatures, and the orange-red tones showing

the higher temperatures. After quality masking, pixels that did not have a valid observation were not spatially interpolated, but kept as no-data, within the principal visualization range of ~20-40°C.

Normalized Difference Vegetation Index (NDVI) is a widely used index for monitoring vegetation.

Normalized Difference Vegetation Index (NDVI) was used to represent the vegetation condition. The Landsat median composite was used to compute NDVI from the near-infrared (NIR) and red (R) surface-reflectance bands:

$$NDVI = \frac{NIR-Red}{NIR+Red}$$

For Landsat 8 and 9,

$$NDVI = \frac{SR_{B5}-SR_{B4}}{SR_{B5}+SR_{B4}}$$

where SR_{B5} is the near-infrared reflectance and SR_{B4} is the red reflectance. NDVI values can range from −1 to +1 with more positive values generally corresponding to more photosynthetically active vegetation (PAV) abundance. The visualization range was approximately −0.2 to 0.6 to be able to represent the maps of Luanda.

The resultant NDVI raster was interpreted spatially to view vegetation pattern and also used for subsequent pixel-based study to investigate the relationship between vegetation and LST. NDVI was interpreted as a vegetation-density indicator rather than as a measure of tree canopy or specific types of green space as is common in remote-sensing applications (Weng et al., 2004; Yuan & Bauer, 2007).

Normalized Difference Built-up Index

The Built-up Index (NDBI) was assessed to measure built-up and spectrally urban-like surfaces:

$$NDBI = \frac{SWIR1-NIR}{SWIR1+NIR}$$

This was done for Landsat 8 and Landsat 9 as:

$$NDBI = \frac{SR_{B6}-SR_{B5}}{SR_{B6}+SR_{B5}}$$

where SR_{B6} is the short-wave infrared band 1 and SR_{B5} is the near-infrared reflectance. The range of visualization was chosen to be approximately −0.3 to 0.4.

The NDBI was interpreted with caution as spectrally bright bare and dry surfaces can show a similar response to built-up surfaces, especially in dry climate and low vegetation cover areas. Built-up indices derived from conventional method have already been shown to have issues to separate constructed surfaces from bare soils under such circumstances (Rasul et al., 2018). For this reason, the NDBI layer was used as an indicator for the intensity of built-up surfaces and their spectral characteristics and was analysed alongside the independently generated urban-centre extent layer, NDVI layer, and LST layer.

Urban expansion assessment

The urban-expansion was based on the multi-temporal GHS-WUP-MTUC polygons for the year 2000 and 2025 with reference to Luanda. By using the persistent Luanda urban-centre identifier, the corresponding records were selected and exported in a separate vector layer.

The two epochs were then overlaid in QGIS to show the spatial direction and extent of metropolitan expansion. The 2000 urban extent was plotted as a semi-transparency filled polygon and the 2025 boundary was plotted as an outline to maintain the visibility of the 2000 extent.

The related AREA_km2 field of the table of GHS-WUP-MTUC statistics was also kept for quantitative comparison. Percentage change in urban-centre area was defined as:

$$Urban\ growth\ (\%) = \frac{A_{2025}-A_{2000}}{A_{2000}} \times 100$$

A_{2000} and A_{2025} are the urban-centre areas reported for the respective periods. The numerical results are not included in the methodological description but in the Results and Discussion section.

Water masking and statistical analysis based on pixels.

The Modified Normalized Difference Water Index (MNDWI) was computed as: to investigate the relationship between vegetation and surface temperature while minimizing the effect of open water pixels on the statistical structure.

$$MNDWI = \frac{Green-SWIR1}{Green+SWIR1}$$

or, for Landsat 8/9,

$$MNDWI = \frac{SR_{B3}-SR_{64}}{SR_{B3}+SR_{B6}}$$

The analysis of the correlation between NDVI and LST was performed by excluding pixels having a value of (MNDWI \geq 0). Further plausibility filters were applied to keep the observations made on the ground within the range of 0 to 0.8 in NDVI and 20°C to 45°C in LST.

To get a random sample of 5,000 valid 30-m pixels, a fixed random seed of 42 was used for the sake of reproducibility. The Pearson's product-moment correlation coefficient was determined between NDVI and LST:

$$r = \Sigma[(x_i - \bar{x})(y_i - \bar{y})] / \sqrt{[\Sigma(x_i - \bar{x})^2 \times \Sigma(y_i - \bar{y})^2]}$$

where x_i is NDVI and y_i is LST.

A simple linear regression model was then developed:

$$LST_i = \beta_0 + \beta_1 NDVI_i + \varepsilon_i$$

Coefficient of determination (R2) was statistically calculated to quantify the percentage of the LST variance that was statistically related to NDVI in the linear model fitted. Google Earth Engine was used to generate scatter plots with linear trend lines.

A general sampling framework was used to assess the feasibility of conducting an exploratory NDBI–LST analysis. With seed 42, 5,000 pixels were sampled and again Pearson correlation and simple linear regression were performed, with the difference that the pixels that were not water were identified by MNDWI, and NDBI was limited from −0.3 to 0.4 and LST was limited to 20-45°C. Due to the potential of confusion of NDBI with bare surfaces in dry environments, this relationship was considered exploratory and not as reliable as the NDVI–LST analysis (Rasul et al., 2018).

Use of map products and map processes

The analytical workflow comprised of four key spatial products as well as two statistical visualizations. Temporal urban expansion was represented using urban-centre polygons, while the conditions of

LST, NDVI and NDBI were represented using rasters derived from Landsat data for the year 2025. The statistical analysis tested the relationship between NDVI–LST, and, exploratory, between NDBI–LST by scatter plots and Pearson correlation and linear regression.

The primary raster outputs were all created at 30-m resolution and downloaded from Google Earth Engine in GeoTIFF format. To enable visual comparisons between the environmental indicators, the same spatial extents and similar figure layouts were also maintained. Masked pixels were not spatially interpolated nor was causal inference used in interpretation, but spatial association.

RESULTS AND DISCUSSION

Growth of Luanda in urban sprawl from year 2000 to 2025.

The multi-temporal GHS-WUP-MTUC data show a significant spatial growth of Luanda urban centre from 2000 to 2025. The reported urban-centre area grew from 289 km2 in 2000 to 1,039 km2 in 2025, an increase of some 259.5%. In the same period, the built-up component reported in the data grew by around 155.2% from around 123.96 km² to 316.30 km². These values reflect a significant growth in the metropolitan footprint beyond that which would be expected for simple urban consolidation.

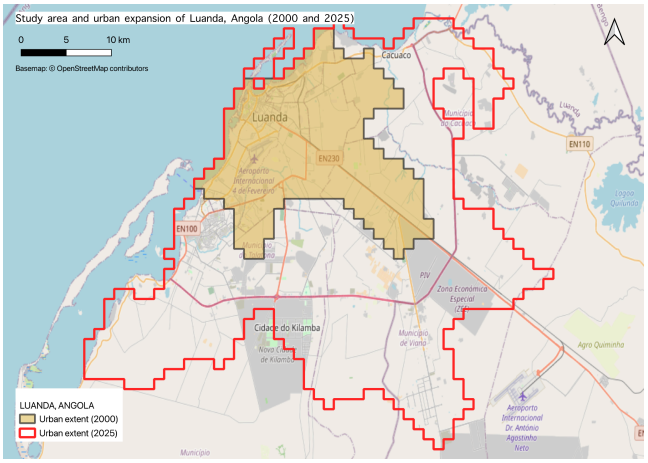

Figure 1. Study area and urban sprawl of Luanda (2000 and 2025).

Figure 1 shows that the period 2000–2025 urban-centre area is more spread out than that of 2000, especially in the southern, south-east and north-east sides of the metropolitan region. The pattern suggests a shift from a relatively dense coastal urban structure to a markedly larger and more geographically spread out metropolitan structure. Areas that were previously on the fringe of the city are part of the expansion, and the expansion is a result of the development of new residential, transportation and mixed-use areas.

This finding aligns with previous evidence by Ngolo and Watanabe (2023) who identified very high rates of growth of Luanda's built-up area in the first two decades of the twenty first century. In their analysis, they calculated that in 2018, the land extent covered by built up areas had reached around 468.4 km², up from 94.5 km² in 2000 and attributed urban expansion to residential development, transportation corridors, and government supported housing programmes. While the spatial definitions and datasets are distinct in that study, and those used here, both analyses indicate a similar overall process of the metropolitan restructuring of Luanda rather than its gradual infill development.

This observed growth has significant environmental implications since the increase of the urban footprint alters the balance between vegetated, bare and impervious surfaces. The changes in land cover may affect the exchange of surface energy and, potentially, alter the spatial distribution of heat (de Almeida et al., 2021; Weng, 2009). But the extent of thermal change is not only dependent on the urban expansion. For this purpose, the LST patterns, NDVI and NDBI patterns for contemporary were analyzed separately.

Land Surface Temperature (LST) in space

The 2025 LST map derived from Landsat data shows significant temperature variations across the city of Luanda and its surrounding area. Surface temperatures in the visualization range were widely distributed from ~20°C to 40°C and higher; the warm and hot surfaces are indicated by orange to red colors.

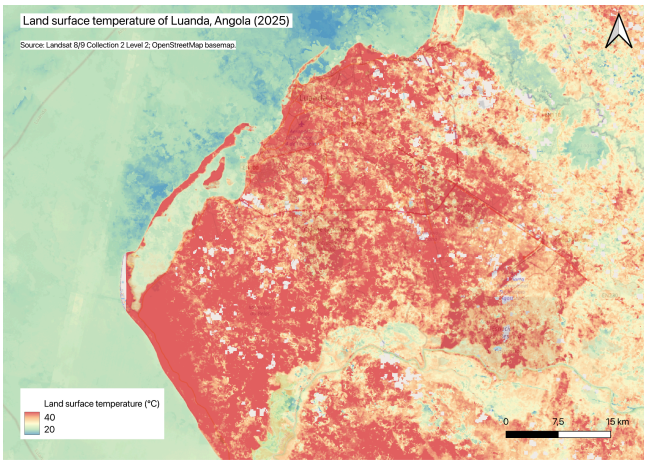
Land surface temperature of Luanda, Angola (2025)
Source: Landsat 8/9 Collection 2 Level 2; OpenStreetMap basemap
Land surface temperature (°C)
40
20
0 7.5 15 km

Figure 2. Luanda, Angola - Land surface temperature in 2025.

As seen in Figure 2, there are high LST areas throughout the metropolitan area. The increased surface temperatures are especially noticeable in areas with dense and sparse vegetation cover, but are not limited to the urban center. High LST is found on some peripheral and exposed surfaces as well. In contrast, lower surface temperatures are found in regions that are related to higher vegetation availability, water influenced environments, and selected peripheral landscapes.

The spatial configuration is relevant as it shows that Luanda is not solely understood by a contrast of urban versus rural temperatures. Dry or bare surfaces outside of heavily developed areas can be very hot when the Landsat image is taken during the day, while vegetated or water influenced areas inside or around an urban area may be fairly cool. This is used to emphasize that there is a difference between a map of the land surface temperature patterns and the formally calculated surface urban heat island intensity.

Surface temperature has been shown to highly depend on the land-cover composition, the availability of vegetation, moisture and the thermal properties of urban materials (Weng et al., 2004; Yuan & Bauer, 2007). In a similar manner, Manoli et al. (2019) demonstrated that the strength and pathways of urban warming are different in different climatic backgrounds and depending on the difference in evapotranspiration between urban and surrounding surfaces. The thermal patterns observed in Figure 2 are therefore likely to be the result of a combination of the above factors inherent in Luanda's multi-faceted combination of built-up areas, exposed soils, vegetation and wet environments.

Results also corroborate the necessity of careful urban-heat interpretation in African cities. Ngie et al. (2014) and Gyimah (2023) pointed out the usefulness of using remotely sensed LST to recognize the spatial thermal difference in African urban environment and also the importance of taking cognizance of local environmental conditions. The present results in Luanda suggest that spatial thermal exposure is not uniform and that it is probably influenced not only by urban development but also by the interaction between a number of surface features.

The distribution of vegetation and the relationship of NDVI with LST

The NDVI analysis on the study area shows that the vegetation density is significantly different across the area. Values between about −0.2 and 0.6 were displayed, with low or negative values indicating that the area was water, exposed surfaces or areas of low vegetation and higher values indicating that there was more vegetation present.

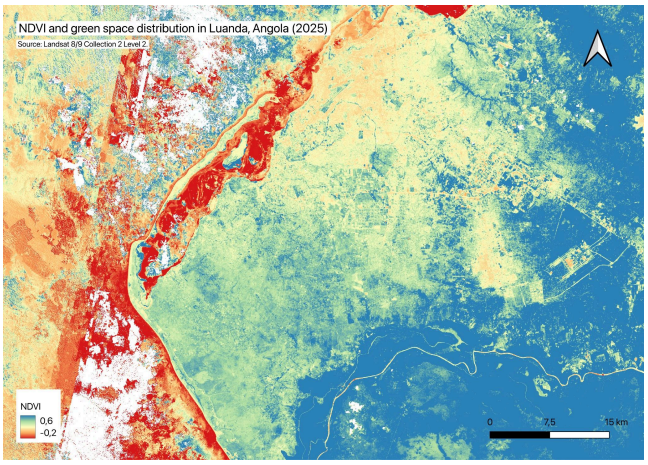

Figure 3. NDVI and green space distribution in Luanda, Angola (2025).

As seen in Figure 3, the central and western parts of the metropolitan area are very urbanized and have mostly low to moderate vegetation signals. There is a greater presence of higher NDVI values toward the eastern and southeastern side of the study area and in other local vegetated areas. This spatial pattern indicates that the distribution of green cover in Luanda's wider metropolitan area is not even.

Figures 2 and 3 clearly illustrate that a few regions of higher vegetation index values relate to "cooler" surface temperatures while a group of regions of lower vegetation index values are related to "warmer" surface temperatures. A subset of 5,000 randomly selected terrestrial pixels (excluding water pixels, and with the plausibility thresholds as described above) was analysed to determine if this visual relationship was statistically detectable.

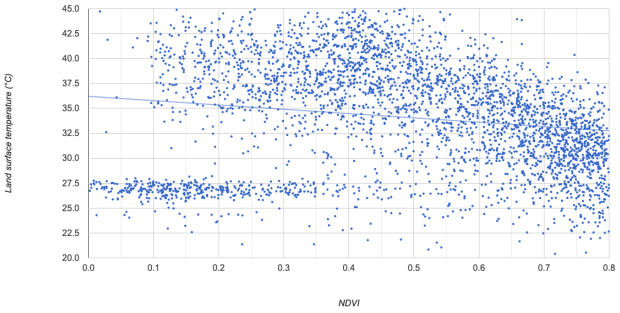

Figure 4. Correlation between NDVI and LST for the region of Luanda, Angola (2025).

The Pearson analysis resulted in a correlation coefficient of:

$$r = -0.168$$

with:

$$R^2 = 0.028$$

The regression equation was found to be:

$$LST = 36.204 - 4.320 \times NDVI$$

The regression coefficient is negative, suggesting that an increase in the NDVI was generally associated with a decrease in surface temperature. Using the linear model, a one-unit increase in NDVI is statistically equivalent to a LST decrease of ~ 4.32°C. The changes in observed NDVI in cities usually are smaller than one unit, so this coefficient is not necessarily to be considered as an intervention effect, but rather as the slope of the statistical model.

The relationship is still weak, however. With an R2 value of ~0.028, the linear range of the sampled LST is explained by NDVI at only about 2.8%. Thus, the results do not confirm the hypothesis that the spatial structure of Luanda's temperature is exclusively related to vegetation density. Rather, they show a weak and measurable cooling connection.

This finding agrees with the theoretical and empirical studies indicating an inverse relationship between NDVI and LST for many urban areas (Weng et al., 2004; Yuan & Bauer, 2007), as well as revealing the context-dependency of this relationship. In Luanda, bare soil, building materials, urban density, moisture conditions, proximity to water and coastal effects and spatial arrangement of land-cover types can also affect the surface temperature. Also, Manoli et al. (2019) showed that the cooling effect of vegetation and the thermal behaviour of urban surfaces are not universally applicable but rather are influenced by climatic conditions.

Importantly, the first correlation that was made, prior to removal of the water and less desirable pixels, was a weak positive correlation. Once the MNDWI-based water exclusion and terrestrial plausibility filtering were used, the direction was reversed to the theoretically expected negative association. This shows the methodological value of isolating similar surfaces on the land in coastal urban studies. When a simple city-wide NDVI–LST correlation includes ocean/lagoon or other aquatic pixels, it can affect the statistical relationship, as water surfaces have spectral and thermal properties that are different from the urban surfaces on land.

NDBI patterns and built-up surface characteristics

The NDBI map has been generated in order to offer another built-up (and spectrally similar dry surface) representation throughout Luanda. Data were displayed for values lying in the range of about −0.3 to 0.4, with higher positive values being conventionally considered to represent higher built-up spectral response.

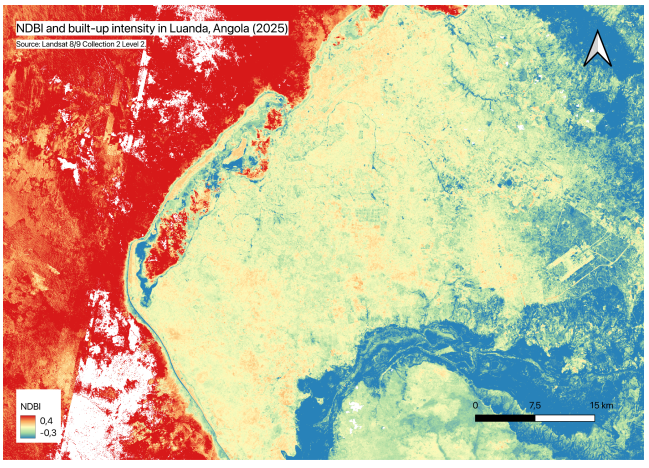

Figure 5. NDBI and built-up intensity for Luanda in Angola (2025).

Figure 5 shows a much more complicated pattern than a simple expectation that the highest NDBI values would only be found in the most urbanised parts of Luanda. Many exposed peripheral surfaces have high NDBI values and the majority of the metropolitan core has moderate or mixed values. This indicates that the index is sensitive to built-up surfaces as well as dry and spectrally bright land-cover classes.

This finding is in line with the limitations noted by Rasul et al., (2018), who showed that NDBI has some problems distinguishing

built-up areas from bare soil in dry climate urban areas. Similar near-infrared and short-wave infrared reflectivity relationships can be obtained for both materials. This methodological issue is of special relevance in Luanda, where there are large areas of exposed and poorly vegetated surfaces.

It is important to note, therefore, that the NDBI product should not be used to precisely map building density. Rather, it contains data on built-up surface and dry surface spectral intensity, which needs to be analysed in combination with the GHSL urban extent and NDVI layers. This distinction is significant as an uncritical interpretation of NDBI may assign 'strongly built-up' to highly exposed non-urban surfaces.

The relationship between NDBI and surface temperature.

This limitation is also highlighted by the exploratory pixel-based analysis of NDBI and LST.

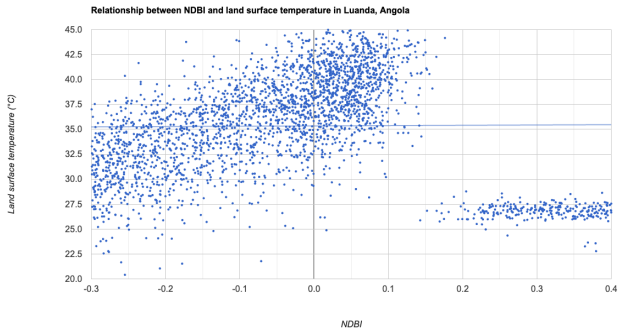

Figure 6. Relationship between NDBI and land surface temperature in Luanda, Angola (2025).

The Pearson correlation coefficient was:

$$r = 0.010$$

and the coefficient of determination was:

$$R^2 = 0.0001$$

The regression equation that was fitted was approximately:

$$LST = 35.343 + 0.317 \times NDBI$$

Statistically, it means that there is practically no linear relationship between NDBI and LST over the selected Luanda study area. The NDBI values account for only approximately 0.01% of the LST variability and the relationship appears to be rather weak within the current sampling framework.

This interpretation is supported by the scatter plot. The sampled observations do not create a continuous linear distribution but instead cluster. There is one set of observations with relatively high NDBI values, and relatively low and clustered temperatures, and another set of observations with low to moderate NDBI values and much more spread out temperatures. This type of clustering is not indicative of the assumption of a uniform built-up intensity across the study area as measured by NDBI.

This result does not detract from the overall analysis, but rather is an important methodological finding. It shows that care should be taken when using conventional NDBI to understand urban thermal relationships in Luanda. Conceptual shortcomings for dry climate city were also noted by Rasul et al. (2018), which included spectral confusion between bare soil and built surfaces. The Luanda results show that the data provided by GHSL are able to support this caution: the conventional NDBI–LST relationship is hardly visible when considered at the broader heterogeneous landscape, despite the significant urban growth evidenced by the GHSL data.

The comparison with the NDVI results is also telling. The correlation value of NDVI was found to be weak but clearly negative with LST ($r = -0.168$), while that of NDBI was found to be almost non-existent ($r = 0.010$). This indicates that so far, the vegetation abundance index is a slightly better spatial thermal variation index for Luanda than is the conventional NDBI; but both indexes have low to moderate explanation of the LST variability.

Comprehensive interpretation of urban development and thermal conditions.

The combined spatial and statistical analysis showed a large metropolitan-scale spatial expansion in Luanda and also revealed high contemporary thermal heterogeneity. The GHSL urban-centre extent grew by around 259.5% from 2000 to 2025, and the built-up surface indicator grew by around 155.2%. Meanwhile, the 2025 Landsat analysis reveals high-temperature surfaces spread across the landscape and vegetation distribution is uneven.

Table 2. Summary of major quantitative results

Indicator	Result
Urban-centre area, 2000	289 km^2
Urban-centre area, 2025	1,039 km^2
Change in urban-centre area	+259.5%
Built-up area, 2000	123.96 km^2
Built-up area, 2025	316.30 km^2
Change in built-up area	+155.2%
NDVI–LST Pearson correlation	$r = -0.168$
NDVI–LST coefficient of determination	$R^2 = 0.028$
NDBI–LST Pearson correlation	$r = 0.010$
NDBI–LST coefficient of determination	$R^2 = 0.0001$

The results thus do not lend to an explanation that is too naive, that is, recent urban expansion per se leads to a spatial uniformity in thermal response. This rather suggests a complicated urban environmental system, where the interaction of vegetation, bare soil, water influence, coastal position, impervious surfaces and urban morphology is responsible for the observed temperature distribution.

However, the low correlation between NDVI and LST should not be used to assume that urban vegetation is of little importance. The negative sign of the association is the opposite of what was to be expected, as vegetation should cool the thermal environment, while the low R2 shows thermal conditions are influenced by many other factors. Planning-wise, this implies that urban greening is not a stand-alone solution and should be considered as part of a bigger heat-management approach. They can be protection and development of green spaces, protection of heat-sensitive locations in spatial planning, urban-tree systems, permeable surfaces, and spatial configuration of development and preservation of water-influenced cooling spaces.

There are also elements related to the green economy in such interventions. Spatial environmental assessment can be used to identify areas where public and private resources may provide more environmental benefit, given limited resources. The importance of linking geospatial environmental assessment with economic exposure and sustainability-oriented investment decisions has been proven in earlier studies (Qadimli et al., 2026), and research in the field of green-finance shows that financial instruments can play a vital role in the development of environmentally beneficial infrastructure and low-carbon economy (Sadiqov et al., 2026). NbEI approaches can also enable urban NbEI, if there is spatial evidence that a priority area for action exists (Qadimli & Mammadov, 2026).

The conclusions, in general, confirm the need for integrated urban environmental monitoring. The sources of urban environmental stress are not often monogenic, and earlier studies have indicated that industrial activity, transportation activity, construction, and expansion of urban areas in general can interact to affect environmental quality (Arifzade et al., 2026). This is, again, the case of urban thermal conditions in Luanda where the surface temperature should be regarded as a result of interplaying land-cover and urban-development processes, and not of one spectral index.

However, there are some limitations to the analysis. Firstly, the LST, NDVI, and NDBI layers are a median composite of January-April 2025 and not necessarily the annual mean climatic conditions. Second, the satellite-derived LST is surface radiative temperature, and thus differs from the near surface air temperature that residents directly experience. Thirdly, building height, local climate zones, detailed socioeconomic exposure or in-situ temperature observations are not included. Fourth, it is clearly seen that there is spectral mixing of dry soil and constructed surfaces in the study area that affects NDBI. Lastly, the statistical associations presented here are spatial associations, and no conclusions can be drawn about causality.

Nevertheless, a combination of multi-temporal GHSL urban data, thermal and spectral data derived from Landsat, and pixel-based statistical analysis offers a reproducible framework and approach for the evaluation of environmental characteristics observed during the rapid urbanization process in Luanda. The main finding is not that there is a single urban heat-island effect, but that there is a highly heterogeneous thermal landscape associated with rapid metropolitan growth that demonstrates only weak cooling relationships with vegetation and poor surface-temperature prediction relationships with conventional NDBI.

CONCLUSIONS

In this study, the spatial linkage between urban expansion, land surface temperature, vegetation conditions and built-up intensity of Luanda, Angola, was evaluated using an integrated remote-sensing and geospatial approach. The multi-temporal GHS-WUP-MTUC data were overlaid with the Landsat 8 and Landsat 9 Collection 2 Level 2 data to analyze the dynamics of urban expansion from 2000 to 2025, and to create land surface temperature (LST), Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-up Index (NDBI) indicators for 2025. The analysis shows that Luanda has undergone significant metropolitan growth and has a very complex thermal structure in the present day.

According to the GHS-WUP the urban-centre area has grown from about 289 km² in 2000 to 1,039 km² in 2025 (an increase of about 259.5%). The built-up component has grown from about 123.96 km2 to 316.30 km2, that is, by 155.2%. A spatial comparison reveals that development was not just limited to the former small urban area, but stretched to the south, south-east and north-east sections of the metropolitan area. Such patterns reinforce that the recent growth of Luanda has been one of marked sprawl rather than densification, per se.

The LST analysis for the year 2025 showed significant spatial variations, and a few dense developed areas with low plant cover and exposed surfaces showed high daytime temperatures. Simultaneously, cooler environments were linked to more vegetated, moisture-influenced or water adjacent environments. Results indicate thus that the thermal geography of Luanda does not fit in a straightforward dichotomy between urban and non-urban land. The observed temperature distribution is likely to be influenced by the interaction between the above factors, including the influence of coastal effect, vegetation, exposed soil and surface moisture, urban morphology and construction attributes.

There was a measurable but relatively weak relationship between vegetation and surface temperature. The NDVI–LST analysis was done after excluding water pixels and implausible observations, and resulted in a Pearson correlation of $r = -0.168$ and $R^2 = 0.028$. Based on the fitted regression model, $LST = 36.204 - 4.320 \times NDVI$, an overall tendency of higher vegetation density to be related to lower surface temperature is observed. But NDVI accounted for only approximately 2.8% of the observed LST variation, which indicates that in Luanda's case other factors besides vegetation must be taken into consideration to explain the complex thermal structure. The outcomes still uphold the potential benefits of urban vegetation as a part of a larger heat-mitigation plan.

The NDBI analysis resulted in a different outcome. No significant correlation was found between NDBI and LST ($r = 0.010$, $R^2 = 0.0001$). The weak association and spatial distribution of NDBI values suggests that conventional NDBI is not a good standalone surface temperature predictor over Luanda's heterogeneous landscape. This is probably due to spectral confusion between built-up surfaces and exposed soil and other dry land features. Therefore, caution should be used in interpreting NDBI in similar urban areas with low to moderate moisture, and its use should be combined with other built-up datasets or more sophisticated classification methods if available.

The results indicate that Luanda's fast growth needs to be complemented by increased consideration of the spatial distribution of vegetation, open space and water-based cooling environment and heat sensitive urban design in planning context. Although there is a weak statistical correlation found in this study, urban greening and expanding tree cover, protecting existing trees, and promoting permeable surfaces and climate-responsive land use planning may help decrease localized thermal stress, but should not be considered a single solution. The spatially focused environmental assessment can also be used to steer future investments in green infrastructures and other urban interventions that can help make cities resilient to climate change.

There are some caveats to be considered. The Landsat indicators for 2025 are a January–April median composite and not annual climatic averages. Satellite-derived LST should not be thought of as equivalent to near surface air temperature or direct human heat exposure as it measures radiative surface temperature. Building height, local climate zones, detailed land-use categories, socioeconomic vulnerability or in-situ temperature observations are also not included in the study. Moreover, the urban-centre representation for 2025 is part of a harmonized multi-temporal representation and should not be considered as an administrative boundary. While they limit causal interpretation, they do not diminish the study's value for spatial assessment of the patterns in the contemporary urban environment.

Future work should include longer time series and seasonal LST observations, local climate zone (LCZ) classification, more detailed built-up mapping and field-based temperature verification and socioeconomic exposure assessment. Adding population density, green space access and building morphology and heat-sensitive infrastructure would enable the step from spatial thermal mapping towards a more general urban heat-risk framework. The study overall shows the potential value of combining GHSL, Landsat, Google Earth Engine and QGIS for exploring smart and fast urban transformation in data-poor metropolitan regions, and offers a replicable platform for future urban planning and sustainable urban development in Luanda, responding to the changing climate.

AUTHOR CONTRIBUTIONS

Conceptualization, N.Q. and U.M.; methodology, U.M.; data curation, U.M.; formal analysis, U.M.; investigation, N.Q. and U.M.; visualization, U.M.; writing—original draft, U.M.; writing—review and editing, N.Q. and U.M.; supervision, N.Q. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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The authors also acknowledge the U.S. Geological Survey (USGS) for providing freely accessible Landsat 8 and Landsat 9 Collection 2 Level 2 imagery used to derive land surface temperature, vegetation and built-up indicators.

The authors further acknowledge the Google Earth Engine platform for providing the cloud-based computational environment required for satellite-image filtering, preprocessing, spectral-index calculation, pixel sampling and statistical analysis. Appreciation is also extended to the developers and contributors of QGIS, which was used for geospatial visualization, cartographic processing and preparation of the final publication-quality maps. The authors additionally recognize the OpenStreetMap contributors whose openly available geographic information supported contextual cartographic representation in selected figures.

The availability of these open-access Earth observation datasets, geospatial platforms and open-source analytical tools substantially facilitated the reproducibility and spatial consistency of the present research and contributed to the assessment of urban expansion and surface thermal patterns in Luanda, Angola.

REFERENCES

Arifzade, E., Mammadov, U., & Abbasova, G. (2026). Economic and ecological analysis of the relationship between PM2.5 and PM10 levels and industrial and transport factors in the cities of Sumgayit and Almaty. *Journal of Economics, 3*(2), 14–22. https://doi.org/10.36719/3104-4727/7/14-22

de Almeida, C. R., Teodoro, A. C., & Gonçalves, A. (2021). Study of the urban heat island (UHI) using remote sensing data/techniques: A systematic review. *Environments, 8*(10), 105. https://doi.org/10.3390/environments8100105

Earth Resources Observation and Science (EROS) Center. (2020). *Landsat 8–9 Operational Land Imager/Thermal Infrared Sensor Level-2, Collection 2* [Data set]. U.S. Geological Survey. https://doi.org/10.5066/P9OGBGM6

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment, 202*, 18–27. https://doi.org/10.1016/j.rse.2017.06.031

Gyimah, R. R. (2023). The hot zones are cities: Methodological outcomes and synthesis of surface urban heat island effect in Africa. *Cogent Social Sciences, 9*(1), 2165651. https://doi.org/10.1080/23311886.2023.2165651

Manoli, G., Fatichi, S., Schläpfer, M., Yu, K., Crowther, T. W., Meili, N., Burlando, P., Katul, G. G., & Bou-Zeid, E. (2019). Magnitude of urban heat islands largely explained by climate and population. *Nature, 573*, 55–60. https://doi.org/10.1038/s41586-019-1512-9

Mammadov, U. (2025). An empirical analysis of youth knowledge and perceptions of green finance: Evidence from Azerbaijan. *Journal of Economics, 2*(4), 49–53. https://doi.org/10.36719/3104-4727/5/49-53

Melchiorri, M., Freire, S., Schiavina, M., Florczyk, A., Corbane, C., Maffenini, L., Pesaresi, M., Politis, P., Szabo, F., Ehrlich, D., Tommasi, P., Airaghi, D., Zanchetta, L., & Kemper, T. (2024). The multi-temporal and multi-dimensional Global Urban Centre Database to delineate and analyse world cities. *Scientific Data, 11*, 82. https://doi.org/10.1038/s41597-023-02691-1

Ngie, A., Abutaleb, K., Ahmed, F., Darwish, A., & Ahmed, M. (2014). Assessment of urban heat island using satellite remotely sensed imagery: A review. *South African Geographical Journal, 96*(2), 198–214. https://doi.org/10.1080/03736245.2014.924864

Ngolo, A. M. E., & Watanabe, T. (2023). Integrating geographical information systems, remote sensing, and machine learning techniques to monitor urban expansion: An application to Luanda, Angola. *Geo-spatial Information Science, 26*(3), 446–464. https://doi.org/10.1080/10095020.2022.2066574

Pesaresi, M., Schiavina, M., Politis, P., Freire, S., Krasnodębska, K., Uhl, J. H., Carioli, A., Corbane, C., Dijkstra, L., Florio, P., Friedrich, H. K., Gao, J., Leyk, S., Lu, L., Maffenini, L., Mari-Rivero, I., Melchiorri, M., Syrris, V., Van Den Hoek, J., & Kemper, T. (2024). Advances on the Global Human Settlement Layer by joint assessment of Earth Observation and population survey data. *International Journal of Digital Earth, 17*(1), 2390454. https://doi.org/10.1080/17538947.2024.2390454

Qadimli, N., & Mammadov, U. (2026). Assessing ecosystem sustainability and green finance-based ecotourism opportunities in Akhar-Bakhar National Park. *Journal of Green Economy and Optimization Research, 1*(1), 1–13. https://doi.org/10.5281/zenodo.21921560

Qadimli, N., Rasulov, Z., Mammadov, U., & Hasilov, E. (2026). Satellite-based assessment of water level variability and economic exposure in Azerbaijan's Caspian Sea and strategic inland water systems. *American Journal of Environmental Economics, 5*(2), 31–45. https://doi.org/10.54536/ajee.v5i2.8204

Rasul, A., Balzter, H., Ibrahim, G. R. F., Hameed, H. M., Wheeler, J., Adamu, B., Ibrahim, S., & Najmaddin, P. M. (2018). Applying built-up and bare-soil indices from Landsat 8 to cities in dry climates. *Land, 7*(3), 81. https://doi.org/10.3390/land7030081

Sadiqov, E., Qadimli, N., & Mammadov, U. (2026). Green finance instruments for supporting solar energy development in Azerbaijan. *American Journal of Energy and Natural Resources, 5*(1), 18–26. https://doi.org/10.54536/ajenr.v5i1.7984

Schiavina, M., Alessandrini, A., Melchiorri, M., & Dijkstra, L. (2025). *GHS-WUP-MTUC R2025A – GHS-WUP multitemporal urban centres, obtained from the Degree of Urbanisation grids (GHS-WUP-DEGURBA R2025A) and linked across epochs, multitemporal (1950–2100)* [Data set]. European Commission, Joint Research Centre. https://doi.org/10.2905/1ea967e5-bedc-4cf3-a0b0-3851742ee7e2

Shi, H., Xian, G., Auch, R. F., Gallo, K., & Zhou, Q. (2021). Urban heat island and its regional impacts using remotely sensed thermal data—A review of recent developments and methodology. *Land, 10*(8), 867. https://doi.org/10.3390/land10080867

Weng, Q. (2009). Thermal infrared remote sensing for urban climate and environmental studies: Methods, applications, and trends. *ISPRS Journal of Photogrammetry and Remote Sensing, 64*(4), 335–344. https://doi.org/10.1016/j.isprsjprs.2009.03.007

Weng, Q., Lu, D., & Schubring, J. (2004). Estimation of land surface temperature–vegetation abundance relationship for urban heat island studies. *Remote Sensing of Environment, 89*(4), 467–483. https://doi.org/10.1016/j.rse.2003.11.005

Yuan, F., & Bauer, M. E. (2007). Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. *Remote Sensing of Environment, 106*(3), 375–386. https://doi.org/10.1016/j.rse.2006.09.003

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Digitalization of financial control in budget organizations and evaluation of its impact on socio-economic development indicators

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financial control, digitalization, budget organizations, socio-economic development, risk-based analytics, state funds, transparency.

ABSTRACT

The study is devoted to the analysis of the phenomenon of the digitalization of financial control mechanisms in budget organizations, its study and assessment of the potential role in the efficiency, transparency, accountability and socio-economic effectiveness of public financial management. Particular emphasis is laid on the shift from a traditional, ex-post financial control to an automated, preventive and risk-based monitoring system, which can help to make decisions more quickly and on the basis of evidence. The research method that is used is qualitative and comparative analysis of existing and new financial management mechanisms such as the automated control platform, the processing system based on Big Data, the system of support and analysis by artificial intelligence, the continuous auditing system and the Key Risk Indicators. In addition, the study examines how integrated public databases and cross-platform data exchanged can enhance the accuracy and timeliness of financial oversight. The results show that the use of digital financial control instruments helps to identify financial irregularities early, minimize human-related errors, enhance financial discipline and increase budget expenditure efficiency. Automated and risk-based control mechanisms also enable the possibility of a change in the public financial oversight paradigm from a punitive to a preventive approach, where potentially suspicious transactions can be detected before any financial loss occurs. Besides, digitalization can help better allocate public resources and better target expenditure in strategically important areas like education, health care, social protection, regional development and infrastructure. The study also reveals that an increased degree of integration between treasury, procurement, taxation and other public information systems could help to build greater transparency and improve the quality of public services. Meanwhile, the research reveals a number of challenges that remain, such as the lack of interoperability between public databases, the lack of application of advanced predictive analytics and the lack of proper integration of socio-economic performance indicators with financial controls. The research finds that the creation of a comprehensive and fully integrated Digital Financial Control system, with Artificial Intelligence, automated reporting, continuous audit and performance monitoring can help in the more transparent public financial management, better utilization of the state resources and more sustainable socio-economic development.

INTRODUCTION

The efficiency, transparency and accountability in the use of public funds is a basic precondition for sustainable socio-economic development. Government budgets are the medium through which the national development priorities are expressed in monetary terms, and thus, the size and quality of the public sector's role in education, health, social protection, infrastructure, environmental protection, regional development and other priorities. Financial control in budget organizations therefore fulfills a much wider role than verification of accounting documents, such as fiscal discipline, public accountability, efficient allocation of resources and ultimately the quality of public services.

The Law of the Republic of Azerbaijan on the Budget System (2002) serves as the legal basis for budget preparation, budget execution, budget reporting and budget control in Azerbaijan. The law establishes the general organizational, economic and legal structure in which budgetary resources are built up and utilized. However, with financial transactions becoming more numerous and more complex, additional control measures are required other than periodic inspection based on documents. Today's public finance systems, more than ever, demand for integrated databases, electronic audit trails, automated verification, real time monitoring, and risk-based analytical capability.

This transformation has seen its relevance increase in Azerbaijan after the institutionalization of the “Digital Public Finance” Information System (RDMIS). The Regulation adopted in 2026 defines the legal, organizational and technological conditions of the RDMİS, and includes provisions to leverage digital technologies to enhance efficiency, transparency, accessibility, analytical capabilities and information exchange in the budget, taxation, customs, accounting, audit, public financial control, treasury operations, public debt and financial liabilities (President of the Republic of Azerbaijan, 2026). RDMİS thus constitutes a significant institutional measure in the direction of establishing one public financial management ecosystem.

International experiences also show that the path to integrated and data-driven public financial management is one of a progressive evolution from separated financial information systems. Rivero del Paso et al. (2023) highlight that digital transformation of public financial management needs both functional processes and information technology architecture to be developed, as well as governance and management capacity. More recently, Pattanayak et al. (2026) put forth that a clear institutional strategy with the introduction of emerging technologies such as artificial intelligence, advanced analytics, automation, and integrated data infrastructures can reinforce fiscal discipline, allocative efficiency, operational efficiency, transparency, and accountability.

The World Bank (2026) further states that Financial Management Information Systems (FMIS) are systems that facilitate the automation and integration of the budget formulation, budget execution, treasury operations, accounting and financial reporting processes. An integrated platform could offer a more complete picture of government financial activity, if FMIS is integrated with other information systems like procurement, payroll, debt management etc. This integration opens up new opportunities for identifying irregularities and for reinforcing linkages between financial decision and development outcomes.

But digital transformation shouldn't be judged solely on software adoption. The OECD (2025) highlights the strategic and outcome-driven governance of public investment in digital technologies, the capacity of institutions to deploy and manage it, risk management, and public value. Likewise, the PEFA Secretariat (2016) assesses public financial management in terms of budget reliability, transparency, control in budget execution, accounting and reporting, and external scrutiny and audit. These principles point towards the fact that digitalization should add value to the overall financial management system and not just replace paper based process with electronic ones.

In recent years, the research of Azerbaijani scientists confirmed the growing application of integrated economic, financial, social and environmental indicators, which shows the relevance of such approach. For instance, Mammadov (2025) assesses knowledge and perceptions of green finance focusing on the human and behavioural aspect of financial transformation. Sadiqov et al. (2026) explore the role of financial instruments in supporting solar energy development, highlighting the influence of financial mechanisms on sustainable investment outcomes. In addition to that, Qadimli and Mammadov (2026) incorporate ecosystem sustainability with green finance-based ecotourism opportunities, whereas Qadimli et al. (2026) use satellite-derived environmental information along with economic exposure indicators. Arifzade et al. (2026) also use an integrated approach of economic and ecological analysis to evaluate air pollution and its linkages with industrial and transport factors.

While they do not directly address financial control in budgeting, they do illustrate an emerging methodologic pattern: both financial and economic decisions are being judged by a variety of outcome indicators. This principle has a direct impact on modern public financial management as the focus of effective financial control is becoming increasingly concerned with whether money was spent in line with the law and whether it was spent in a way that created a measurable public value.

Digital transformation requires a focus on human and institutional aspects. In his study on digital banking service quality, Rustamov (2026) demonstrates the connection between technological development, operational efficiency, and user experience in the financial services industry. Samadova and Gasimov (2026) highlight the significance of financial competency of professionals, the international accounting standards and transparency in financial reporting. The implications for the public sector are that the success of digital financial control relies on staff who can understand the automated outputs, handle data, assess risks and ensure accurate financial reporting.

In this context, the main goal of this study is to analyse the process of digitalisation of the financial control mechanisms in budget organisations and assess its impact on socio-economic indicators of development. The overall purpose of the study is to:

1. discuss the theory and institutional basis of financial control in digital environment;
2. Discuss the difference between the old and new (digital, risk based) methods of financial control;
3. evaluate the new structure of Azerbaijan's public finance management in the digitization process;
4. Note down ways in which digital financial control can help in making expenditure more efficient, transparent and accountable;
5. Assess possible connections between financial control and the socio-economic development outcomes; and
6. identify policy and institutional solutions to create an integrated digital financial control ecosystem.

LITERATURE REVIEW

Public financial management in the transition to digital.

The process of digitalising public financial management is a shift from both isolated administrative automation and toward integrated information-driven governance. With traditional financial administration, budget planning, procurement, treasury execution, accounting, reporting and auditing can be performed by different systems and institutional processes. This fragmentation can lead to delays, duplication, reconciliation issues and information asymmetries between institutions.

Rivero del Paso et al. (2023) suggest a holistic framework for digital PFM, which consists of three interdependent pillars: functional design, IT architecture and governance and management. This framework is especially critical, as technically sophisticated systems may not have an impact on financial management if the underlying processes are disjointed, or institutional roles are not defined.

Pattanayak et al. (2026) build on this debate by looking at the future of public financial management in the context of emerging technologies. They suggest that AI, deep analytics, automation, open data, and other technologies have a role to play in boosting data-informed decision making across the budget process. The authors, however, note that the choice of technology must be based on well-defined PFM goals rather than on technology adoption alone.

The World Bank (2026) too emphasizes integration. FMIS can be used for the automation of budget formulation, commitment control, treasury management, accounting and reporting; and integration with other PFM can provide a centralized environment to process and analyze financial transactions on a day-to-day basis. This is especially significant from a financial control standpoint as discrepancies could be hard to detect in one system but come to light when data from multiple systems are compared.

Financial Management and Performance in Public Sector

Financial control should not be viewed in isolation of the general goals of public financial management. The Secretariat of the PEFA (2016) highlights three basic budgetary outcomes: fiscal discipline at the aggregate level, strategic allocation of resources, and efficient service

delivery. These outcomes link the financial control with socio-economic development in an important conceptual manner.

A control system for preventing uncalled for or wasteful spending makes a direct contribution to fiscal discipline. More reliable information for allocation of resources helps to strategic allocation. A system for the effective delivery of resources to the intended institutions and activities indirectly supports efficient service delivery.

OECD (2025) also strongly recommends to consider digital government investments in the context of strategic objectives and measurable public value. Thus, the success of a digital financial control should not be measured just by automated transactions and digital modules. The real question is whether digitalization makes for more efficient, transparent, reliable and developmental impact financial management.

The shift from ex-post control to risk based monitoring

Traditional financial control is mostly a 'look-back' control. Financial transactions are made, documents are prepared, reports are submitted and then auditor(s) determine if financial operations have met applicable requirements. This approach is critical for accountability, but it can be used to only know about an issue once it has a financial impact.

Digital financial control allows for potential continuous and risk-based monitoring. Trades can be automatically checked against pre-defined parameters and analysed based on Key Risk Indicators (KRIs). It can be for anything from an increase in the number of payments sent to the same supplier, repeated payments to the same supplier, spending above and beyond a predetermined amount, spending that does not match the supplier classification, or a spike in spending at the end of the fiscal period.

Pattanayak et al. (2026) note that AI and advanced data processing could be significant tools to redesign public financial management processes. Rivero del Paso et al. (2023) also highlight the importance of automation and data-driven financial management to minimize manual errors and strengthen control over expenditures.

It is important to differentiate between a risk indicator and actual financial misconduct. An automated red flag does not automatically mean that there is a violation. Instead it should focus on transactions for extra verification. So digitalisation does not replace the professional judgement – it frees up human time for activities with higher risk.

Table 1. Comparing traditional and digital risk-based financial control features

Evaluation criterion	Traditional financial control	Digital / risk-based financial control
Inspection frequency	Periodic, scheduled or annual	Continuous or near-real-time monitoring
Data coverage	Mainly sampling-based	Potential analysis of the full transaction population
Timing	Predominantly ex-post	Ex-ante, concurrent and ex-post possibilities
Main information source	Documents and manually submitted reports	Integrated electronic databases and transaction records
Analytical approach	Manual verification and professional examination	Automated screening, KRI analysis, anomaly detection and AI-supported analytics
Human intervention	High in routine control activities	Reduced in routine verification; focused on complex and high-risk cases
Risk identification	Often detected during or after inspection	Automated alerts and early warning mechanisms
Cross-checking	Manual comparison between documents/systems	Automated cross-database verification
Reporting	Periodic	Automated and more frequently updated
Main orientation	Compliance and detection	Compliance, prevention, risk management and performance
Audit trail	Document-dependent	Continuous electronic traceability
Decision support	Primarily retrospective	Potentially predictive and preventive

The academic works in the fields of finance and sustainability in Azerbaijan also offer valuable insights that complement the broader context of digital financial control.

Rustamov (2026) illustrates how digitalization can impact the quality of financial services and their efficiency. Although it is not the same as public financial administration, digital banking shares common traits with these, including system reliability, process automation, accessibility, speed, and user-centric service.

The relationship between professionally oriented financial education, adoption of IFRS, employability and reporting transparency is studied by Samadova and Gasimov (2026). Their study emphasizes the importance of human capital development along with the institutional and technological reforms in the process of financial modernization. Digital financial control also needs auditors and financial officers to be able to work with data analytics, automated reporting, digital accounting systems, and risk models.

In the context of green finance, it is important to note the role of financial knowledge and awareness, which are emphasized by Mammadov (2025). The study indirectly reinforces the overall point that financial innovation needs not only instruments and technologies, but also institutional and individual competencies to comprehend and apply these instruments and technologies correctly.

Other research shows the increasing importance of multidimensional analysis techniques. Sadiqov et al. (2026) makes connections between financial instruments and renewable energy development. Qadimli and Mammadov (2026) assess the ecosystem sustainability and the opportunities of green finance and ecotourism. Qadimli et al. (2026) use environmental observations and economic exposure, while Arifzade et al. (2026) look at the connections between pollution indicators and economic activity.

The significance of these studies for the present work is not necessarily the fact that they are directly relevant to the issues of budget control, but rather that they are methodologically oriented. They illustrate that modern economic thinking is making more and more connections between financial investments and tangible social, environmental and/or economic results. Public financial management can be done in a similar way: link expenditure information with performance indicators.

MATERIALS AND METHODS

Research design

Qualitative analytical, comparative and institutional research design is used. It does not provide causal impact of digital financial control based on econometric data at the transaction level. It, however, looks at how digital technologies can change financial control and what possible pathways there are between technology and spending efficiency and socio-economic impact.

This design is suitable because Azerbaijan's integrated RDMİS architecture is in transition and the study aims to present an analytical framework to assess the transformation, not to provide empirical measures that could not be empirically separated at this stage.

Source base

The research is based on three sources of research.

The first group includes national regulatory and institutional sources, such as the Law of the Republic of Azerbaijan on the Budget System (2002), the Regulation on the "Digital Public Finance" Information System (President of the Republic of Azerbaijan, 2026), the report on the activities of the Chamber of Accounts in 2025 (Chamber of Accounts of the Republic of Azerbaijan, 2026).

The second are international methodological and institutional sources on digital public financial management and PFM performance such as the PEFA Framework (PEFA Secretariat, 2016), the IMF Digital Solutions Guidelines for Public Financial Management (Rivero del Paso et al., 2023), OECD Framework for managing digital government investments (OECD, 2025), the IMF Study on the use of Emerging Technologies in Public Financial Management (Pattanayak et al., 2026), and the World Bank Framework for Managing Public Financial Management Systems (FMIS) (World Bank, 2026).

The third one is recent academic research from the Azerbaijan context on financial digitalization, financial literacy, reporting transparency, green finance, sustainability, multidimensional economic assessment (Mammadov, 2025; Arifzade et al., 2026; Qadimli & Mammadov, 2026; Qadimli et al., 2026; Rustamov, 2026; Sadiqov et al., 2026; Samadova & Gasimov, 2026).

Analytical dimensions

The collected material was analysed under six different dimensions:

- Interoperability of financial data between treasury, budget, accounting, procurement, taxation, audit, other public data bases.
- The ability to conduct regular financial checks without manually verifying these checks.
- Utilization of KRIs, anomaly detection, Big Data analysis and AI-supported approaches to prioritize potentially risky transactions.
- The capacity to detect issues before they reach an irretrievable financial sink-hole.
- The capacity to implement sound electronic audit trails, enhance reporting and to establish institutional accountability for financial decisions.
- Capacity to link financial costs and investments to tangible outputs and socio-economic impacts.

These dimensions were chosen because all align well with the salient PFM goals that are captured by PEFA (2016), the proposed digital PFM architecture by Rivero del Paso et al. (2023), and the evolving technology framework put forward by Pattanayak et al. (2026).

Financial control workflow for concepts.

The study recommends five stages in the digital financial control process based on the information analyzed from the sources.

1. The data on finances and administration are obtained on the basis of budget preparation, procurement and contracts, execution of treasuries, accounting, tax records, invoice and payroll, as well as sector-specific information systems.
2. Secure system interface to transfer relevant information to an integrated financial data environment. The goal is not to necessarily store all of the data sets in one database, but to make sure that all of the data sets are interoperable in a standardized and secure manner.
3. The basic compliance tests are carried out automatically. These can include approval of budget restrictions, categories of spending, supplier details, conformance of invoices, mandatory authorisation and more.
4. Transactions are assessed with the help of KRIs and if necessary, statistical/machine-learning models. Transactions are assigned higher control priority if they exhibit abnormal characteristics.
5. Professionally examined for high risk operations and validated information is included in financial and performance reporting. Financial data can also be cross-referenced with KPIs at this stage showing service delivery or socio-economic outcomes.

RESULTS AND DISCUSSION

Improving the integrated digital public finance environment in Azerbaijan. According to the analytical review, Azerbaijan is progressing towards a more integrated approach to digital public financial management. The most important recent institutional development is RDMİS, which explicitly paves the way for combining and analyzing information on the state budget, taxation, customs, accounting, audit, public financial control, treasury operations, state debt, and other financial obligations (President of the Republic of Azerbaijan, 2026).

This is significant because the main benefit of an integrated system isn't just its electronic storage of monetary data. Its chief benefit is that it can link data that has been stored in different institutional contexts.

As an example, a procurement transaction can generate data in a procurement system, a contractual system, an invoice, a tax record, a treasury payment record, an accounting record, and ultimately, an audit record. These data are still disjointed and will therefore need to be manually compared to verify if correct or not. Selected characteristics can be automatically compared if it is integrated accordingly.

The Chamber of Accounts of the Republic of Azerbaijan (2026) still has very important role in external public financial control, assessment of budget execution. More advanced digital data sharing within internal finance systems and external audit processes may facilitate a transition towards real-time and risk-based oversight.

The Azerbaijani direction conforms to international trends. Integrated functional and technological architecture in the digital PFM is crucial, as noted by Rivero del Paso et al. (2023), and the integration of FMIS with other public financial systems is also a key mechanism for enhancing transparency and accountability, as per World Bank (2026).

Table 2. The key elements of an integrated digital financial control system.

Component	Main function	Control benefit
RDMİS	Integrated public finance data	Centralized monitoring
Budget systems	Budget planning and allocation	Spending control
Treasury systems	Payment execution	Prevents excess spending
E-procurement	Digital procurement	Transparency and competition
Tax & e-invoice systems	Transaction verification	Cross-checking
Accounting systems	Financial recording	Accurate reporting
Audit platforms	Risk analysis	Targeted auditing
Performance systems	KPI monitoring	Links spending to outcomes

Digital systems can have pre-defined controls in place prior to the completion of a transaction. Expenditure requests are automatically matched with approved budget limits and classifications, meaning

that routine errors can be caught earlier. This isn't the end of all irregularities, yet it does lessen reliance on retrospective confirmation.

Predictability and control in budget execution are one of the key tenets of good public financial management, as identified by the PEFA Secretariat (2016). Digital financial control reinforces this aspect by means of the possibility to incorporate transaction level controls into the operation systems.

The World Bank (2026) also highlights the importance of FMIS for budget execution, commitment control, treasury management, accounting, and reporting. These functions can help minimize discrepancies between the approved expenditure, commitments, payments and accounting records.

Financial control based on risk and prevention

The second important discovery is the change in the timing of control.

The traditional audit approach does not have the capacity to audit each transaction in real time. Automated screening of a higher percentage of transactions, however, is possible on a digital platform. This makes it possible to continuously classify risk.

AI and emerging technologies are identified as potential tools to automate validation, analytical processing and decision support in public financial management by Pattanayak et al. (2026). It's not a matter of blocking all suspicious activity, it's about recognizing the activity that warrants professional scrutiny.

A viable KRI system could involve:

- unusual transaction frequency;
- recurring payments to a single supplier over short periods of time;
- duplicate invoice characteristics;
- increased or decreased spending significantly from the historical pattern;
- out-of-scope spending, which includes money spent outside of the scope of the budget headings; and
- sudden changes in contractor payment behavior;
- A high focus of spending at the end of the fiscal year; and
- Data inconsistencies between procurement, invoice, tax and treasury information.

One great advantage of such a system is the prioritization of audit resources. High risk transactions can be given immediate attention and routine, low-risk transactions can be given less administrative attention.

But automated risk models can give false positives. Hence, digital control should be used as a decision support system. But human auditors will still be required to be responsible for interpreting context, obtaining evidence and deciding if a transaction is truly non-compliant.

Controlling finances and efficiency of resources.

The third impact pathway relates to expenditure efficiency.

There is an opportunity cost of public goods: when public goods are wasted in one area, there are fewer resources for other needs. Thus, avoiding double payments, overpayments, procurement inefficiencies or mis-targeted spending may present an opportunity for fiscal space.

According to OECD (2025), it is crucial to make sure that investments in the digital public sector create value. This is true of public spending, in general. Financial control should not just focus on whether money was spent, but more and more consider whether the money was spent efficiently or not as a use of public funds.

This shift reflects the overall shift towards performance-based public financial management. PEFA Secretariat (2016) ties good PFM to effective allocation of resources and efficient service delivery. Therefore, the digital financial control can make a direct contribution to development not by means of the technology itself, but by better allocation and utilisation of resources.

Connection with socio-economic development indicators

The fourth and most crucial analysis pathway is the financial control and socio-economic outcomes.

The study suggests that this relationship is regarded as a sequential mechanism:

Digital financial control – better compliance and information quality – reduced leakage and inefficiency – better resource allocation – better service delivery – socio-economic outcomes.

For instance, better control of educational spending does not necessarily lead to better educational outcomes. But it can help improve the odds that allocated funding is spent on the schools, equipment, digital connectivity or other approved purposes.

Likewise, for healthcare, more efficient procurement and verification of payments can save financial inefficiencies which can be channeled into service delivery. In social protection, integrated information systems can enhance targeting and minimize over- or under-payments. Infrastructure: More control over procurement and payments for projects can enhance accountability during implementation.

Table 3. Digital financial control to socio-economic outcomes and potential pathways.

Area	Digital control tool	Potential effect
Education	Expenditure monitoring	Better resource use
Healthcare	Payment verification	Reduced financial risks
Social protection	Beneficiary verification	Better targeting
Infrastructure	Contract monitoring	Higher accountability
Regional development	Expenditure analysis	Better allocation
Environment	Performance monitoring	Efficient green spending
Public administration	Automated reporting	Higher efficiency
Procurement	Digital analytics	Greater transparency

The relevance of performance oriented analysis is also indirectly confirmed by the latest literature of Azerbaijan. Qadimli et al. (2026) show the way of evaluating economic exposure in conjunction with environmental change, and Arifzade et al. (2026) integrate environmental and economic factors in the same framework. In the same context, Qadimli and Mammadov (2026) incorporate sustainability and financial aspects when assessing ecotourism potential.

The link between financial instruments and the development of renewable energy is illustrated by Sadiqov et al. (2026), which highlights that financial assessment can be conducted in the context of sustainability in the real sector. Mammadov (2025) points to the significance of financial awareness and understanding for financial transformation.

What the studies have taught us is that not all financial indicators should be analyzed separately. This implies that, in the case of public financial control, indicators of budget execution can more and more be connected to output and outcome indicators for each sector.

Training and institutional development

Digital financial control relies greatly on human resources. While automation can decrease the need to even manually check things, it can also increase the demands on other skills. Financial control staff need to be knowledgeable on digital accounting systems, database structures, data visualization, statistical analysis, information security, and automated audit techniques.

According to Samadova and Gasimov (2026), the importance of developing professionally oriented financial education and financial reporting competence in terms of transparency and employability is emphasized. This argument is directly relevant to public institutions: financial information systems, and especially those of a sophisticated nature, can produce bad control results if employees are unable to read and interpret the information that they produce.

Rustamov (2026) also shows that the quality of digital financial services is not just based on technology availability but on the effectiveness of implementation and user interaction. The same goes for public financial management. Even the most sophisticated systems can be rendered useless if they are poorly designed, inadequately trained, if different individuals are responsible for different aspects of the system, or if there is little or no user acceptance.

To this end, systematic professional development should be part of digital transformation, which should involve, inter alia:

- data analytics;
- Advanced Excel and database management;
- SQL;
- risk modeling;
- audit analytics;
- A basic Python or similar analytical tool;
- cybersecurity awareness;
- digital accounting;
- visualization and interpretation of dashboards; and
- AI-assisted financial analysis.

Transparency and accountability

Digitalization can also enhance transparency through the creation of more comprehensive audit trails. Electronic systems can be used to track the date of creation, modification, approval, payment and reporting of a transaction. This enhances the likelihood of finding the culprits and tracing the money trail when the audit is done.

Transparency and accountability are potential benefits of integrated FMIS according to the World Bank (2026). Transparency and good governance in digital PFM operations are also highlighted by Rivero del Paso et al. (2023).

The relevance of RDMİS in Azerbaijan is particularly high as the implementation of RDMIS involves the systematization and accessibility of information in the financial sector and optimization of public financial administration (President of the Republic of Azerbaijan, 2026).

Transparency, however, does not mean the free publication of all financial information. Digital public finance comprises institutional, commercial and possibly personal information. Thus, an effective transparency means classification of information, secure control of access and appropriate publication of non-confidential information.

Cyber security & data governance.

A fractured system can be inefficient, but a very integrated system can have serious repercussions if it isn't sufficiently cyber secure. If any of these are compromised, it could have a devastating effect on the fiscal administration and on public trust.

Therefore, a digital financial control system should include:

- role-based access control;
- multi-factor authentication;
- encryption;
- Backup and Disaster recovery;
- Unchangeable or secure audit logs;
- periodic cybersecurity testing;
- segregation of duties;
- data quality validation;
- incident response procedures; and,
- continuous personnel training.

Rivero del Paso et al. (2023) explicitly consider IT architecture and governance as part of the digital PFM. Pattanayak et al., (2026) also stress the need for coming technologies to be implemented in a systematic way, taking into account feasibility, risk, institutional capacity and sustainability.

Proposed integrated model

The analysis leads to the development of an integrated digital financial control model, comprising of four layers of interdependent activities.

Layer 1 – Integrated financial data infrastructure.

RDMİS should be an interoperability environment that links up to pertinent budget, treasury, accounting, procurement, tax, audit and other financial information.

Layer 2 – Automation of compliance control.

Whenever possible, requirements for routine legal and financial issues should be codified as clear automated validation rules.

Layer 3 – Risk-based analytical control.

Financial risk should be classified with the help of KRI systems, statistical techniques and time-tested AI models for targeted audit.

Layer 4 – Performance and socio-economic monitoring.

There is a need to close the loop between financial information and programme outputs and some key socio-economic indicators – especially in the implementation of performance-based budgeting.

The model takes the focus away from the question, “Was the money legally spent?” and toward the following broader sequence:

Was the money spent properly? → Was it carried out properly? → Was it efficient? → What was the result? → What public value was gained?

Policy and practical suggestions

A number of priorities are suggested based on the results of the research. Firstly, facilitate the use of interoperability in RDMIS. The integration should be built around a standardized set of data structures and secure APIs to ensure that financial information relevant to the integration can be easily compared across institutions without any manual data transfers.

Second, put transparent KRI-based monitoring upstream of the complex AI systems. Rule based risk indicators are more easily explainable and verifiable. They can then be complemented by machine-learning models when adequate high quality historical data are available.

Third, set up ongoing audit systems. Automated screening should be followed all throughout the budget execution process, not only after the annual reporting.

Fourth, combine financial control and performance based budgeting.

Financial expenditure and measurable outputs and KPIs should be linked over time in budget organizations.

Fifth, build capacity of professionals.

Regular training for auditors, accountants, and public financial managers should be provided on digital analytics, database management, cybersecurity, automated audit techniques, and interpreting AI-generated audit findings.

Sixth, develop strong data governance and cybersecurity standards. Clear rules should be established around data ownership, access, validation, retention, and protection along with the interoperability.

Seventh, enhance open financial reporting, as far as lawfully permitted.

More and more, aggregated, non-confidential information should be made available in machine-readable formats for public analysis and oversight.

Eighth, assess digitalisation based on outcomes and not just on the software. The most significant indicators of the success of RDMİS and related reforms should be improvements in fiscal discipline, expenditure efficiency, transparency, audit quality, public service delivery and relevant socio-economic indicators.

CONCLUSIONS

The study shows that digitalization of financial control in budget organizations is not merely a technological modernization, but rather a transformation of institutions. With the development of integrated systems for public financial management, there is an opportunity to shift away from a fragmented, periodic, and predominantly retrospective approach to continuous, data-driven, risk-based and increasingly preventive financial oversight.

RDMIS development is an essential institutional basis for this transition in Azerbaijan. The system has the potential to reduce fragmentation of information and provide a more robust analytical foundation for financial decision making by integrating information pertaining to budgetary management, taxation, accounting, audit, treasury management, public financial control, and other areas.

Based on the analysis, the use of digital financial control can enhance the budgetary discipline, increase transaction traceability, speed up cross-database verification, facilitate risk-based audits and minimize routine human factor errors. In the long term, however, its greatest impact could be on resource allocation. Financial leakages and inefficiencies can be minimised and expenditure can be more transparent and measurable, thus enabling public resources to be used more effectively in education, health and social protection, infrastructure, regional development and sustainability.

Meanwhile, the study also indicates that technological infrastructure will not guarantee good financial governance. Data quality, interoperability, professional expertise, cybersecurity, institutional collaboration, risk-model validation, and accountability are still critical. AI and automated risk systems should therefore be used in addition to, and not as substitutes for, professional judgement in the audit process.

Another contribution of the study is that financial control is integrated in a socio-economic performance analysis. Future public financial control systems should be increasingly able to measure not only adherence to spending rules, but also the correlation between public expenditure inputs, public sector services outputs and development outcomes.

In particular, the research is qualitative and conceptual. The study does not apply transaction data from the budget organizations and hence does not attempt to estimate causal effects in terms of savings or socio-economic improvements from digital financial control. This restriction can be significant, especially since the digital public finance structure in Azerbaijan is still in its early stages.

Audits and treasury, procurement and budget execution data should be used in the future to measure the performance of specific risk indicators (anonymised). Empirical studies might involve assessing the level of irregularities found before and after the implementation of automated control measures, quantifying the reduction in processing time, measuring the difference in the price of procurement and assessing the correlation between financial efficiency and socio-economic indicators of each sector.

In general, the creation of an interoperable, secure, risk-based and performance-based digital financial control environment can be an important part of sustainable public financial governance in Azerbaijan. As technology reform is coupled with institutional development and human capital investment, digital financial control can enhance transparency and accountability and boost the ability of public finances to deliver measurable socio-economic value.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Arifzade, E., Mammadov, U., & Abbasova, G. (2026). Economic and ecological analysis of the relationship between PM2.5 and PM10 levels and industrial and transport factors in the cities of Sumgayit and Almaty. *Journal of Economics International Scientific Journal, 3*(2), 14–22. https://doi.org/10.36719/3104-4727/7/14-22

Chamber of Accounts of the Republic of Azerbaijan. (2026). *Report on the activities of the Chamber of Accounts of the Republic of Azerbaijan in 2025*. https://sai.gov.az/hesabat-xulasesi

Law of the Republic of Azerbaijan on the Budget System, No. 358-IIQ. (2002). *Collection of Legislation of the Republic of Azerbaijan*. https://e-qanun.az/framework/1126

Mammadov, U. (2025). An empirical analysis of youth knowledge and perceptions of green finance: Evidence from Azerbaijan. *Journal of Economics, 2*(4), 49–53. https://doi.org/10.36719/3104-4727/5/49-53

OECD. (2025). *Effectively managing investments in digital government: An OECD policy framework*. OECD Public Governance Policy Papers, No. 76. OECD Publishing. https://doi.org/10.1787/5c324e91-en

Pattanayak, S., Rivero del Paso, L., Tourpe, H., & Cho, C. (2026). *Harnessing emerging digital technologies toward a new frontier of public financial management*. Technical Notes and Manuals, 2026(006). International Monetary Fund. https://doi.org/10.5089/9798229040440.005

PEFA Secretariat. (2016). *PEFA 2016: Framework for assessing public financial management* (2nd ed.). PEFA Secretariat.

President of the Republic of Azerbaijan. (2026). *Regulation on the "Digital Public Finance" Information System*, approved by Decree No. 590 of January 26, 2026.

Qadimli, N., & Mammadov, U. (2026). Assessing ecosystem sustainability and green finance-based ecotourism opportunities in Akhar-Bakhar National Park. *Journal of Green Economy and Optimization Research, 1*(1), 1–13. https://doi.org/10.5281/zenodo.21921560

Qadimli, N., Rasulov, Z., Mammadov, U., & Hasilov, E. (2026). Satellite-based assessment of water level variability and economic exposure in Azerbaijan's Caspian Sea and strategic inland water systems. *American Journal of Environmental Economics, 5*(2), 31–45. https://doi.org/10.54536/ajee.v5i2.8204

Rivero del Paso, L., Pattanayak, S., Uña, G., & Tourpe, H. (2023). *Digital solutions guidelines for public financial management*. Technical Notes and Manuals, 2023(007). International Monetary Fund. https://doi.org/10.5089/9798400251566.005

Rustamov, E. (2026). Enhancing digital banking service quality and customer experience in Azerbaijan. *Journal of Green Economy and Optimization Research, 1*(1), 36–41. https://doi.org/10.5281/zenodo.21930845

Sadiqov, E., Qadimli, N., & Mammadov, U. (2026). Green finance instruments for supporting solar energy development in Azerbaijan. *American Journal of Energy and Natural Resources, 5*(1), 18–26. https://doi.org/10.54536/ajenr.v5i1.7984

Samadova, O., & Gasimov, S. (2026). The impact of PMS/ACCA-oriented education and IFRS adoption on graduate employability and financial reporting transparency. *Journal of Green Economy and Optimization Research, 1*(2), 12–18. https://doi.org/10.5281/zenodo.22011418

World Bank. (2026). *Financial Management Information Systems (FMIS)*. World Bank Group. https://www.worldbank.org/en/topic/governance/brief/financial-management-information-systems-fmis

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Assessing green tourism readiness of a riverfront destination in Mingachevir, Azerbaijan

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green tourism, Kura River, Mingachevir, riverfront destination, sustainable tourism

ABSTRACT

Riverfront sites have the potential to stimulate local economic activity and put pressure on local water resources, public spaces, ecosystems, and infrastructure. This study evaluates the green tourism readiness of the city of Mingachevir in Azerbaijan, which is situated on the Kura River and lies beside Mingachevir Reservoir. The type of the study was an indicator-based readiness assessment with qualitative case-study design using secondary data. The analysis combines policy and document analysis with four dimensions: environmental resource base and ecological sensitivity, accessibility and tourism infrastructure, socio-economic inclusion of the local population and green governance and monitoring. The sources included National development documents, environmental documents, Official tourism sources, International sustainability frameworks and most recent peer-reviewed research. The results show that Mingachevir possesses a very rich natural and recreational resource base for river-oriented tourism in terms of its waterfront landscapes, rowing and boating, fishing, birdwatching and available facilities for visitors. But in order to achieve the leap from tourism potential to a sustainable tourism destination it is necessary to have more ecological monitoring, low impact mobility, resource efficient tourism services, waste management, participation of local enterprises, and sustainability indicators at the destination level. The study aims to put forth a practical green riverfront tourism model, incorporating ecological protection, green infrastructure, community value creation, digital & financial accessibility and continuous monitoring. The framework outlines a locally relevant groundwork for riverfront tourism development and conserving the environmental resources the destination relies on in accordance with Azerbaijan's green-growth agenda.

INTRODUCTION

Tourism is now expected to be more likely to stimulate economic development while at the same time delivering economic, environmental and social benefits that do not compromise the resources that destinations rely upon. This is particularly evident in riverfront cities, where recreation, tourism services, urban development, mobility, water management and ecosystem functions share a spatial realm. Hence, a destination's success from a green-economy perspective should not just be judged by the number of visitors and the revenues derived from tourism but also by how efficient and effective resources are being used, the quality of the environment, local inclusion and the long-term resilience of the destination. UNWTO and UNEP have been stressing that green investment in tourism can provide jobs and economic value without applying pressure on energy, water, land and ecosystems (UNEP and UNWTO, 2012).

The dimension of sustainability is especially strong in the case of river tourism, where the river is at the same time an attraction, an ecological system, a public space and an economic resource. Tourist satisfaction and behavioural intentions are influenced by sustainability, accessibility, amenities, and community involvement of river destinations, as revealed by recent research (Nguyen et al., 2026). At the level of the destination, this implies that the development of tourism infrastructure must not be separated from the protection of the ecosystem, mobility, local entrepreneurship and involvement of residents. The literature on sustainable tourism also emphasizes that meaningfully assessing sustainable tourism needs multidimensional indicators instead of only focusing on economic growth (Miller & Torres-Delgado, 2023).

The problems are directly relevant to Azerbaijan. Azerbaijan 2030 national development framework recognizes a clean environment and green growth as one of the national priorities, and the program encourages the use of environmentally friendly technologies, effective use of resources, environmental management development, etc. (President of the Republic of Azerbaijan, 2021). Meanwhile, recent Azerbaijani research more and more draws a link between finance, environmental performance and regional development. For instance, Qadimli and Mammadov (2026) connect ecosystem sustainability with the potential of ecotourism through green finance and Sadiqov et al. (2026) illustrate the potential of green finance instruments to foster investments in renewable energy. This type of work indicates that tourism greening is not just about protecting the environment, but also about investment design, local value creation and quantifiable sustainability results.

There is already a certain tourism base in Mingachevir. According to Official Azerbaijan Travel information, the Kura River and Mingachevir Reservoir are places suitable for water sports, rowing, boating, fishing, recreation by the river and birdwatching, the city has a rowing centre and a rowing boulevard (Azerbaijan Tourism Board, 2026). Meanwhile, water-dependent destinations are subject to ecological and hydrological pressures in which they must be continually monitored. As shown in the Azerbaijan case study by Qadimli et al. (2026), the holistic approach of combining

environmental change with economic exposure in the country's key water systems underscores the need to view water as a dynamic resource rather than as static tourism infrastructure.

Thus, the research problem presented in this paper is not whether or not Mingachevir has tourism potential, but whether or not the existing riverfront and reservoir based assets can be converted into a green tourism model which would be able to reconcile support for ecological functions with sustainable local economic and social benefits. The study poses the following questions: (1) What environmental, infrastructural and socio-economic conditions are currently favorable for development of green tourism in Mingachevir? What conditions can limit the shift from traditional riverfront recreation to green tourism destination model? and (3) What is the possible management framework to further develop the city's green tourism readiness? The study provides a secondary evidence-based indicator-based assessment applicable locally and refrains from making unsubstantiated statements about the perceptions of tourists or residents.

LITERATURE REVIEW

Green tourism; Sustainable destination development

Green tourism may be regarded as a type of destination-development where tourism activity aims at minimizing environmental pressures, while remaining economically viable and socially beneficial. UNEP and UNWTO (2012) link the shift to a green tourism economy with investments in energy and resource efficiency as well as in environmental protection, decent jobs and sustainable infrastructure. This is not just about promoting ecotourism; it is about including accommodation, food services, transport, public space, waste management, water use, energy systems and destination governance.

Sustainability at the destination level must be a balance between visitors, tourism businesses, residents and natural environment. Choi and Sirakaya (2006) showed the usefulness of multidimensional indicator systems which include ecological, economic, social, political, technological and cultural. More recent reviews verify that indicators are most useful when linked with real management choices and are localised (Miller & Torres-Delgado, 2023). Similar multidimensional studies exist within Azerbaijan as well. For the policy analysis, there are other examples of combined environmental and economic indicators, such as the analysis of urban air pollution by Arifzade et al. (2026).

Tourism and the utilization of water resources, as well as local resilience, along rivers.

River tourism is an integration of natural landscape, recreation, mobility, culture and local economy. It is very sensitive to water quality and public waterfront access. The results of Nguyen et al. (2026) by surveying 479 tourists in Can Tho, Vietnam, indicated that community involvement, sustainability, amenities, and accessibility have a significant impact on enhancing tourist satisfaction. Gunawan et al. (2026) also point out the importance of coordination and collaboration between local communities, the government, and the private sector to achieve a balance among nature conservation, local identity, and economic development for river tourism.

The importance of the water-resource dimension for the destination is particularly great for Mingachevir, where the destination is dependent on both the Kura River and Mingachevir Reservoir. The integration of water-level dynamics with economic exposure demonstrates the importance of this approach in understanding the vulnerability of the Azerbaijan's Caspian Sea and strategic inland water systems, and planning for adaptation (Qadimli et al., 2026). Application of this kind of integrated perspective to tourism is relevant, given that varying water conditions can have an impact on recreation, landscape quality, infrastructure and seasonality of water-based activities. However, there is also a need for coordinated water management for the wider Kura Basin, as stated in Strosser et al. (2017).

Investment, local enterprise, and governance with a green approach.

Finance, incentives and local businesses are also necessary as part of the shift towards green tourism. Similarly, Sadiqov et al. (2026) demonstrates how green finance can be used to attract investment in renewable energy, and this can be applied to energy-efficient accommodation, solar-powered visitor facilities and low-carbon tourism services. Financial knowledge and perceptions may impact willingness to use new green financial instruments at the community level (Mammadov, 2025). Digital finance can also enhance access to and quality of services, as evidenced in the case of digital banking in Azerbaijan, where the availability of convenient and reliable financial technologies is crucial for small businesses in the tourism sector to remain user-friendly (Rustamov, 2026).

Other enabling conditions are human capital and reporting quality. Professional competences and transparent financial reporting, which are important in the context of tourism SMEs looking to embrace green standards, record resource savings, or access external financing is highlighted by Samadova and Gasimov (2026). These mechanisms can be backed up by public policy measures, such as suitable fiscal and regulatory incentives. Zeynalova (2019) shows how tax regulation can serve the general development goals of the state in a globalized world and how targeted tax or investment incentives can be part of a larger package of policy measures for a more sustainable tourism industry.

The measurement of tourism sustainability at the local level.

The Statistical Framework for Measuring the Sustainability of Tourism (SF-MST) offers an integrated framework for the organization of economic, social and environmental data at the global, national and subnational level (United Nations & UN Tourism, 2024). How well measurement is translated to destination management depends on the practical value of such frameworks, as described by Dwyer (2024). For riverfront destinations, the local scale is especially significant as the impact of visitors, the waste they generate, the mobility they use and the environmental sensitivity are all concentrated.

The evolutionary nature of tourism areas is another factor a destination management should take into account. Increased visitor intensity can create a greater demand for the resources of the destination, which can be a problem if the management does not keep pace, according to Butler's (1980) tourism area life cycle framework. This provides a helpful planning lesson for a new riverfront destination like Mingachevir: ecological constraints, local gains, and monitoring systems must be put in place before tourism starts to expand at a stage that is hard to reverse.

MATERIALS AND METHODS

This study uses a qualitative case-study approach through secondary data and readiness assessment using indicators. There is no primary survey or interview conducted, no environmental data is measured. The approach was chosen as the target is to understand what assets, gaps, and green tourism management priorities are available, not to statistically estimate tourist attitudes.

Three groups of evidence were reviewed. Initially, the national and international policy and environmental documents were used to set the strategic and ecological context, such as Azerbaijan 2030, Azerbaijan National Ecosystem Assessment, the OECD analysis of the Kura River Basin, and the United Nations' sustainability frameworks.

Secondly, official tourism information was utilized to determine Mingachevir's tourism resources, waterfront facilities and documented activities. Thirdly, the analytical interpretation was enhanced using peer-reviewed literature on sustainable tourism indicators, river tourism, green finance, environmental-economic assessment, and digital financial services.

Green tourism readiness was measured with four dimensions: (1) environmental resource base and ecological sensitivity; (2) accessibility, public space and tourism infrastructure; (3) local economic and social inclusion; and (4) green governance and monitoring. Documentary evidence was used to assess each dimension, using a qualitative framework of Strong, Moderate and Priority Gap. Strong means asset/policy basis is clearly documented, Moderate means relevant capacity is present, but there are gaps in implementation, integration, or evidence and Priority Gap means that management mechanisms, or sufficiently systematic evidence, are not available.

The evaluation is intentionally not quantitative. A composite score was not provided due to the heterogeneity of the documentary evidence and the lack of consistent evidence that provides quantitative measurements at a destination level for all the dimensions. The classifications thus should be seen as structured analytical judgements and not as a statistically derived index. The framework is summarised in Table 1. This restriction is also relevant for interpretation; the study establishes readiness conditions and policy priorities, but does not presume causal impacts on the demand for tourism, resident welfare and environmental quality.

Table 1. Green tourism readiness assessment framework for Mingachevir

Dimension	Assessment
Environmental resource base	Strong; river/reservoir assets, continuous monitoring needed
Accessibility and infrastructure	Strong-Moderate; improve integration and low-impact mobility
Local socio-economic inclusion	Moderate; strengthen local value chains and participation
Green governance and monitoring	Priority Gap; establish destination-level indicators

RESULTS AND DISCUSSION

The base of natural and recreational resources.

The natural and recreational resource base is seen as the strongest dimension of Mingachevir. The Azerbaijan Tourism Board (2026) records various opportunities for rowing, boating, fishing, walking, bird watching and other activities related to nature along the Kura River, Mingachevir Reservoir and associated landscapes. This is also emphasized in the Azerbaijan National Ecosystem Assessment (Abbasov et al., 2023), which highlights the ecological value and the role of freshwater ecosystems in providing ecosystem services, such as habitat and recreation.

This strength cannot be separated from sensitivity to nature. These water systems are also susceptible to alterations in water quality, water quantity, shoreline properties, and human impacts, which affect the value provided to tourism. The importance of integrated approaches to management in the Kura Basin is stressed by Strosser et al. (2017); Qadimli et al. (2026) shows that the hydrological variability should be analysed along with the economic exposure. In the case of Mingachevir, it implies that tourism development should be based on water, and that shoreline condition, litter, pressure of water-based tourism and other indicators relevant for the area should be monitored regularly.

Low impact mobility and infrastructure.

The city of Mingachevir is not a virgin territory but it already has a developed tourism base. The riverside boulevards, rowing facilities, accommodation, food services and water-based activities have been created as a basis for the development of green services (Azerbaijan Tourism Board, 2026). This need does not necessarily mean the development of large structures but rather the environmental upgrading and better integration of existing assets.

Practical measures include pedestrian and cycling connections between waterfronts, energy efficient lighting and public amenities, water conservation measures, visible waste separation facilities, environmentally responsible boating behaviours, and clear visitor information. These measures are in line with the approach of UNEP and UNWTO (2012) towards resource efficiency. Renewable-energy finance also provides opportunities for the tourism industry: the experience of Sadiqov et al. (2026) indicates that the adequate arrangement of green finance instruments can provide an opportunity for investment in solar energy and associated low-carbon technologies.

Involvement of local people and generation of local economic benefit

The socio-economic inclusion aspect is rated as Moderate. River tourism has a potential to create local benefits in accommodation, food services, guiding, recreation, handicrafts, fishing related experiences and small tourism enterprises. However, the documentary sources reviewed are inconsistent in their destination level reporting of the amount of visitor spend that stays in the local economy; how many local suppliers are engaged in the tourism value chain; or how local residents are involved in decisions made about the waterfront. This gap is significant as community involvement is consistently recognized as a key element of sustainable river tourism (Gunawan et al., 2026; Nguyen et al., 2026).

There should therefore be a green model to be linked to enterprise development at the local level. Economic retention can be raised through community-based tourism packages, locally-sourced food, guide training, supporting small business and local procurement without necessitating high-impact physical expansion. This process can be reinforced with financial inclusion. Mammadov (2025) emphasizes the significance of knowledge and perceptions towards the adoption of green finance, and Rustamov (2026) demonstrates the role of accessible digital financial services in enhancing customer experience. For small enterprises, digital payments, transparency of pricing, online booking and access to appropriate financial products can help to function more effectively in the tourism economy.

Professional capacity is also applicable. Any tourism business interested to receive certification, green-finances or public supports must have basic competencies in accounting, reporting and performance measurement. Samadova and Gasimov (2026) thus emphasize professional financial skills and transparency in reporting, which applies to local tourism SMEs. Fiscal measures may also stimulate 'greener' investment through complementarity. As part of this, tax policy as a means of state development, as Zeynalova (2019) has investigated in general, well-thought-out measures could promote investments in energy efficiency, waste reduction, clean mobility and environmentally responsible tourism services.

Green governance and destination-level monitoring.

Green governance and monitoring is the primary Priority Gap. The country has a solid national policy foundation for green growth: Azerbaijan 2030 explicitly emphasizes on development supporting the clean environment, efficient utilization of resources (President of the Republic of Azerbaijan, 2021). The SF-MST offers an international framework for tourism indicators that incorporate environmental,

social and economic aspects (United Nations & UN Tourism, 2024). The challenge lies in turning these general principles into a local system that is in place to monitor.

The sources reviewed provide good information on the tourism resources and the environment in Mingachevir, however they do not present a single publicly visible dashboard for water and shoreline conditions, waste generation, energy and water efficiency, visitor pressure, economic benefit for the region, accessibility and/or resident well-being. Local actors would then be able to transition from project-based interventions towards adaptive destination management by developing such a dashboard. This logic is echoed in other indicator approaches that have been used in Azerbaijani research, such as Arifzade et al. (2026), who integrate environmental and economic factors, and Qadimli and Mammadov (2026), who connect ecosystem sustainability with green finance and the potential of ecotourism.

Green riverfront tourism model that is integrated into the river-front

The result of the assessment leads to the development of a five-component green riverfront model in the case of Mingachevir. First, ecological protection should pinpoint sensitive shoreline and aquatic areas and set up regular ecological observation. Second, low-impact mobility must link the boulevard, park, recreation and visitor services by providing an easy and pleasant walking, cycling and public transportation environment. Third, the green tourism services should promote energy efficiency, saving water and waste, responsible boating and environmentally preferable procurement. Fourthly, a community value component is needed to boost the potential of local SMEs, local guides, food producers and cultural activities. Fifth, a monitoring component should integrate tourism, environmental and socio-economic indicators in a simple local dashboard.

Implementation needs to be gradual. Short-term baseline inventory may document tourism infrastructure, public areas, environmental assets, tourist movement, waste management infrastructure, and accessibility. Medium-term monitoring can include separated waste availability, green businesses participating, local supplier participation, walking and cycling connectivity, and pressure from seasonal visitors. Additionally, more sophisticated indicators can be matched to the SF-MST framework and connected with spatial or environmental data over the longer-term. This phased approach allows for a less complex monitoring system until more basic information collection is reliable.

Managing for seasonality also should be included. Weather and seasonal conditions are factors in water based recreation, and other nature-based uses may have different times of the year when they are optimal. Seasonality in tourism products can spread the load of visitors and stabilize income in the area. First and foremost, Mingachevir should not only be considered a city with a river but a green riverfront city, in which the Kura River and reservoir are viewed as a unified green, ecological, social and economic resource and are managed accordingly. Table 2 provides an overview of the main actions and directions for monitoring proposed by the study.

Funding and implementation issues.

There's also a practical financial arrangement needed for implementing the proposed model. Small tourism enterprises can see their benefits in energy efficiency, solar energy, water-saving equipment and technology or waste reduction technology, yet may not invest because the upfront investment is significant. Green finance evidence in Azerbaijan shows that financial instruments can be used to attract investments for environmentally friendly technologies (Sadiqov et al., 2026). This means destination standards in conjunction with easy-to-access loans, co-financing, or specific support for SMEs that are able to show a reduction in resource usage. The financial awareness is also crucial since the effectiveness of new instruments is contingent on understanding of their costs and benefits by potential users (Mammadov, 2025).

Digital tools can facilitate this process by making payments, bookings, financial bookkeeping and banking services easier, which can lower the barriers to transactions for small tourism operators (Rustamov, 2026). Meanwhile, transparency in reporting and fundamental professional skills are essential if companies are supposed to be compelled to record green investments or to benefit from incentive programs (Samadova & Gasimov, 2026). Financial measures can be supplemented by carefully designed fiscal measures by public authorities. Generally, tax regulation can be development oriented if it is in line with the priorities of the state as Zeynalova (2019) states. Any incentive should, therefore, be conditional, transparent, time-limited, and based on verifiable improvements, rather than just because of the business type, in a green tourism context.

Table 2. Priority actions for green riverfront tourism in Mingachevir

Priority action	Monitoring indicator
Ecological sensitivity map	Sensitive and regulated areas
Walking and cycling links	Route length and access points
Green business standards	Participating businesses
Waterfront waste management	Waste volume and separated share
Community and SME packages	Local suppliers and employment
Annual sustainability report	Economic, social, and environmental indicators

CONCLUSIONS

This study measured the readiness of green tourism for Mingachevir, using the qualitative case-study method and indicator set in four dimensions. The results indicated that City has strong grounds for the development of river-oriented green tourism thanks to the Kura River, Mingachevir Reservoir, waterfront public spaces, recreational opportunities and the existing visitor infrastructure. Meanwhile, key missing areas in destination-level sustainability monitoring, resource efficiency and local economic involvement, and the coordination of tourism, environmental and urban-management functions are identified.

The general policy conclusion is that Mingachevir does not have to exclusively go for a volume-based tourism development. It has a comparative advantage in the provision of a mix of water based recreation and urban access, ecological quality and locally retained economic value. Low impact mobility, resource-efficient tourism services, ecological protection, increased local SME and community involvement, and ongoing monitoring of environmental, social and economic indicators should therefore all be priorities for a green riverfront strategy. Green finance, digital financial services, professional capacity and stimulating, relevant incentives can help to strengthen this transition by making sustainable investment easier for local tourism actors.

The study study limitations are the secondary evidence and qualitative classification. It does not measure visitor satisfaction, residents perceptions, tourism expenditure retention, water quality, carrying capacity or business-level resource efficiency directly. Future studies should thus be based on field observation, GIS analysis, visitors and resident survey, environmental measurements, and business level data. This could enable the readiness framework created here to be translated to a validated spatial and quantitative sustainability index

and would offer greater evidence to support adaptive destination management in Mingachevir and other cities located along rivers.

AUTHOR CONTRIBUTIONS

Conceptualization, methodology, investigation, analysis, writing-original draft, and writing-review and editing, Z.Zeynalova & S.Asgarova.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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DATA AVAILABILITY

All evidence analyzed in this study was obtained from publicly available secondary sources cited in the manuscript. No new dataset was generated.

REFERENCES

Abbasov, R. K., Allahverdiyev, R., Zaynalov, R., Habilov, A., & Aliyeva, R. (Eds.). (2023). *Azerbaijan National Ecosystem Assessment*. Government of Azerbaijan, Regional Environmental Centre for the Caucasus.

Arifzade, E., Mammadov, U., & Abbasova, G. (2026). Economic and ecological analysis of the relationship between PM2.5 and PM10 levels and industrial and transport factors in the cities of Sumgayit and Almaty. *Journal of Economics International Scientific Journal, 3*(2), 14–22. https://doi.org/10.36719/3104-4727/7/14-22

Azerbaijan Tourism Board. (2026). *Mingachevir*. Azerbaijan Travel. https://azerbaijan.travel/mingachevir

Butler, R. W. (1980). The concept of a tourist area cycle of evolution: Implications for management of resources. *The Canadian Geographer, 24*(1), 5–12. https://doi.org/10.1111/j.1541-0064.1980.tb00970.x

Choi, H. C., & Sirakaya, E. (2006). Sustainability indicators for managing community tourism. *Tourism Management, 27*(6), 1274–1289. https://doi.org/10.1016/j.tourman.2005.05.018

Dwyer, L. (2024). Measuring the sustainability of tourism (SF-MST): New wine in an old bottle? *Sustainability, 16*(14), 5867. https://doi.org/10.3390/su16145867

Gunawan, W., Firsanty, F. P., Lesmana, A. C., Nugraha, A. M., Amanatin, E. L., & Lukman, F. (2026). Community-based river tourism development to enhance community empowerment in Serang City. *Social Sciences & Humanities Open, 13*, 102754. https://doi.org/10.1016/j.ssaho.2026.102754

Mammadov, U. (2025). An empirical analysis of youth knowledge and perceptions of green finance: Evidence from Azerbaijan. *Journal of Economics, 2*(4), 49–53. https://doi.org/10.36719/3104-4727/5/49-53

Miller, G., & Torres-Delgado, A. (2023). Measuring sustainable tourism: A state of the art review of sustainable tourism indicators. *Journal of Sustainable Tourism, 31*(7), 1483–1496. https://doi.org/10.1080/09669582.2023.2213859

Nguyen, D. T., Dao, H. D., & Pham, H. D. (2026). Destination sustainability and tourist behavior in river tourism: The role of satisfaction and nationality differences. *International Journal of Tourism Cities, 12*(1), 156–173. https://doi.org/10.1080/20565607.2025.2586148

President of the Republic of Azerbaijan. (2021, February 2). *Order of the President of the Republic of Azerbaijan on approval of "Azerbaijan 2030: National Priorities for Socio-Economic Development"*. https://president.az/en/articles/view/50474

Qadimli, N., & Mammadov, U. (2026). Assessing ecosystem sustainability and green finance-based ecotourism opportunities in Akhar-Bakhar National Park. *Journal of Green Economy and Optimization Research, 1*(1), 1–13. https://doi.org/10.5281/zenodo.21921560

Qadimli, N., Rasulov, Z., Mammadov, U., & Hasilov, E. (2026). Satellite-based assessment of water level variability and economic exposure in Azerbaijan's Caspian Sea and strategic inland water systems. *American Journal of Environmental Economics, 5*(2), 31–45. https://doi.org/10.54536/ajee.v5i2.8204

Rustamov, E. (2026). Enhancing digital banking service quality and customer experience in Azerbaijan. *Journal of Green Economy and Optimization Research, 1*(1), 36–41. https://doi.org/10.5281/zenodo.21930845

Sadiqov, E., Qadimli, N., & Mammadov, U. (2026). Green finance instruments for supporting solar energy development in Azerbaijan. *American Journal of Energy and Natural Resources, 5*(1), 18–26. https://doi.org/10.54536/ajenr.v5i1.7984

Samadova, O., & Gasimov, S. (2026). The impact of PMS/ACCA-oriented education and IFRS adoption on graduate employability and financial reporting transparency. *Journal of Green Economy and Optimization Research, 1*(2), 12–18. https://doi.org/10.5281/zenodo.22011418

Strosser, P., De Paoli, G., & Efimova, T. (2017). *The potential benefits of transboundary co-operation in Georgia and Azerbaijan: Kura River Basin* (OECD Environment Working Papers No. 114). OECD Publishing. https://doi.org/10.1787/a14da8ec-en

United Nations, & UN Tourism. (2024). *Statistical framework for measuring the sustainability of tourism (SF-MST)*. United Nations. https://www.unwto.org/tourism-statistics/statistical-framework-for-measuring-the-sustainability-of-tourism

United Nations Environment Programme, & World Tourism Organization. (2012). *Tourism in the green economy: Background report*. UNWTO. https://wedocs.unep.org/handle/20.500.11822/22015

Zeynalova, Z. Z. (2019). Service functions of tax regulation for the purposes of state development in the globalized environment. *Journal of Advanced Research in Law and Economics, 10*(7), 2190–2197. https://doi.org/10.14505/jarle.v10.7(45).34

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